THE FATE OF FERTILIZER-N APPLIED TO A FLORIDA CITRUS SOIL

By

Daniel Apollo Hagillih

A DISSERTATION PRESENTED TO THE
GRADUATE COUNCIL OF THE UNIVERSITY OF FLORIDA
IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

UNIVERSITY OF FLORIDA

1980

ACKNOWLEDGEMENTS

The author wishes to express his gratitude and appreciation to Dr. R.C.J. Koo, the chairman of his supervisory committee, for his patient guidance in the execution of this research and the preparation of the manuscript. Throughout the graduate training of the author, Dr. Koo strived to imprint on the author an appreciation of the scientific method in research.

The author is equally indebted to Dr. A.H. Krezdorn, Professor Emeritus of Fruit Crops, who had been the Chairman of his supervisory committee. Even in retirement, Dr. Krezdorn continued to serve on this committee and to willingly give of his time, counsel and support. To Dr. W.S. Castle, a member of his committee, the author owes a debt of gratitude and appreciation for his valuable contribution in suggestions, counsel and involvement in all phases of this study.

Sincere appreciation is extended to Dr. N. Gammon, Jr., Professor Emeritus of Soil Chemistry, for his constructive criticism and counsel particularly in the soil aspect of the research. The author also wishes to thank Dr. D.A. Graetz for his assistance in the analysis of soil samples.

The graduate training of the author was sponsored by the Agricultural Research Corporation of the Sudan. Towards the end of his training, the Department of Fruit Crops offered the author a graduate assistantship. He gratefully acknowledges the financial support from both.

Finally, the author wishes to thank Ms. Janice L. Cambridge for her companionship and encouragement throughout the duration of this study.

TABLE OF CONTENTS

	Page
ACKNOWLEDGEMENTS	ii
ABSTRACT	v
INTRODUCTION	1
LITERATURE REVIEW.	3
Nitrogen Balance and Its Major Components . . .	3
Considerations for Increasing the Efficiency of N Usage by Citrus Trees	7
Analytical Procedures for N Balance Components.	10
Isotope Approach to N Utilization by Citrus Trees	15
MATERIALS AND METHODS.	18
Experimental Site	18
Experimental Design	18
Field Sampling Procedures	24
Sample Preparation and Analysis	27
Statistical Analysis.	29
RESULTS AND DISCUSSION	30
Experiments 1 and 2	30
Experiment 3.	70
CONCLUSIONS.	87
LITERATURE CITED	91
BIOGRAPHICAL SKETCH.	103

Abstract of Dissertation Presented to the
Graduate Council of the University of Florida in
Partial Fulfillment of the Requirements
for the Degree of Doctor of Philosophy

THE FATE OF FERTILIZER-N APPLIED TO
A FLORIDA CITRUS SOIL

By

Daniel Apollo Hagillih

March 1980

Chairman: Dr. R.C.J. Koo
Major Department: Horticultural Science

The fate of fertilizer-N applied to Astatula fine sand was studied by the destructive sampling of 1-year-old 'Pineapple' orange (*Citrus sinensis* [L.] Osbeck) trees on 'Alemow' (*C. macrophylla* Wester), and through soil chemical analysis, using the difference method. The fall-winter study involved unfertilized control, isobutylidene diurea (IBDU) and NH_4NO_3 sources in a factorial combination with no irrigation, low and high irrigation levels. Nitrogen source and irrigation treatments lasted for 14 and 6 weeks, respectively. The spring study involved only the 3 N sources and lasted for 6 weeks. Leaf and fruit sampling of bearing 'Pineapple' orange trees, fertilized with the same N sources, and soil

chemical analysis of the unreplicated tree plots were also used. Soil water content in all experiments was determined by a neutron probe.

The results indicated that growth parameters of the young trees, including percent trunk diameter increase, dry weights of component parts and the entire tree, showed no statistical differences attributed to N source, apparently because of the short duration of the studies. There was, however, a trend for IBDU and NH_4NO_3 fertilization to result in greater dry matter, particularly in the more succulent aerial parts. This was apparent in the leaves of the fertilized trees which were statistically greater than those of unfertilized trees.

There was a highly significant relationship between N source and N concentration and total N of tree parts, and total N of the entire tree. In every case, the order of N absorption was NH_4NO_3- > IBDU-fertilized > control trees. This confirms that a soluble source such as NH_4NO_3 is more readily absorbed in the short-term than a controlled release form of N. It is suggested that this trend may not prevail in the long-term.

Irrigation level did not statistically affect tree growth and N content parameters, and soil N content in the fall-winter study. The narrow range and short duration of the irrigation treatments were probably not sufficient to elicit treatment responses.

Nitrogen balance data showed that 66 and 30% of applied N from IBDU and NH_4NO_3, respectively, were retained in the 0- to 60-cm soil profile. Twenty-five and 45% from the same respective sources were accounted for in the young trees. Total apparent N recovery in the soil-plant system was 91 and 76% for IBDU- and NH_4NO_3-N, respectively. The deficit was assumed to have been leached and/or lost to the atmosphere.

There was no difference in fruit yield between IBDU- and NH_4NO_3-fertilized bearing trees. Fertilized trees, however, yielded 4 times as much as the control. Fruit N concentration and removal and leaf N concentration were in the order of NH_4NO_3- > IBDU-fertilized > unfertilized tree. The absence of replication precluded the establishment of a plausible N balance. Nevertheless, 40% of the applied N was estimated to be contained in the fruits and leaves.

High N recoveries on experimental plots involving young, nonbearing, and bearing trees suggest that substantial leaching of N may not be a major route for N loss from citrus groves established on deep, well-drained soils when reasonable rates of fertilizer-N are applied over the root zone.

The potential for a single application of IBDU to young citrus trees, which are normally fertilized several times a year, needs further study.

INTRODUCTION

Florida's sandy soils planted to citrus are characterized by low native fertility which necessitates the regular addition of fertilizer nutrients to maintain a commercial level of production. Such an edaphic environment is also conducive to the substantial leaching of mineral N by rainfall and irrigation (114). Soil tests which measure N carry-over from previous N additions are of little value in these soils. As a result, the replacement of nutrients, including N, lost from the soil is generally dependent upon an evaluation of the need of the crop.

The N requirement of commercial citrus cultivars is based on many long-term investigations in which tree growth and yield were related to fertilizer rate, source, time of application and leaf N content. Nitrogen uptake by the citrus tree is considered to be a small part of the total N loss from the deep, sandy soils of central Florida (100). The efficiency of tree N utilization, i.e., the proportion of N used by the tree compared to that applied, has been estimated to be 25-30%. As a result, there is public and grower concern regarding the quantitative extent of the leaching loss of N applied to citrus. Leached N represents an irretrievable loss of a costly resource and may

contribute to the NO_3^- pollution of underground water and to lake eutrophication.

No meaningful N balance studies, i.e., accounting quantitatively for the fate of N applied to citrus soils as a fertilizer, have been done in Florida as they have in California (29, 68, 69). In order to enhance our understanding of N use in Florida soils planted to citrus, it is essential that the fate of fertilizer-N be studied.

The primary objective of this research was to make a quantitative accounting of fertilizer-N applied to bearing and young trees on a deep, well-drained sandy soil of the Florida ridge area, where much of the citrus in Florida is grown. A second objective was to evaluate isobutylidene diurea (IBDU) as a controlled-release N fertilizer source for citrus.

LITERATURE REVIEW

Nitrogen Balance and Its Major Components

Preliminary Remarks

Important sources for the N in the soil solution include fertilizer-N additions and net mineralization. Other sources also likely to add some N to the soil solution include rainfall, irrigation water, biological fixation, diffusion of atmospheric ammonia into the soil surface, direct absorption of atmospheric ammonia by plant leaves, and transformations involved in the N cycle (80, 125). Major sources of N removal from the soil solution are plant uptake, leaching, net fixation in the soil and denitrification. Smaller losses of N in most agricultural soils include gaseous losses through ammonia volatilization and physical removal by wind and animals.

Attempts to account for the fate of applied N in the soil-plant-atmosphere continuum have yielded some useful information, but it is rare that a complete quantitative recovery of applied N is obtained (2, 50, 97). Calculation of a N balance for a field system is particularly difficult because of the many possible fates of N in soils (65), and because of the physical difficulties encountered in

obtaining quantitative data for some of the major components of a N balance such as leaching, plant uptake and residual N (8, 97).

Leaching of N

Leaching has been defined as the movement of solutes from one soil zone to another by percolated water (107). Leaching of N is important because it represents the loss of a costly resource and because it may contribute to environmental pollution.

Few measurements have been reported giving accurate data concerning nutrient loss from agricultural lands by leaching (34). Most of the mineral N lost by leaching in citrus orchards is in the NO_3^- form (42, 51). The extent of NO_3^- loss from the soil-plant system depends on the fertilizer material, soil type, plant species, rainfall and management practices. High infiltration rates and low water storage capacities of sandy soils make them especially subject to NO_3^- leaching. Other factors which influence the magnitude of NO_3^- leaching include evaporation, nutrient concentration, depth of rooting, N reserves, mineralization of the soil, nitrification of the NH_4-N and soil temperature (113).

In California, the proportion of N applied to citrus leached annually as NO_3^- ranged from 45 (8) to 90% (51). These high NO_3^- leaching losses, however, occurred under conditions of excessive irrigation on well-drained soils

atypical of many irrigated areas in arid zones. In a deep sandy Florida soil, split application of 200 kg/ha of N annually to a mature citrus grove did not result in NO_3^- leaching even when the rainfall was high (35). Studies involving a single annual application of N to evaluate the magnitude of NO_3^- leaching loss from citrus plantings in Florida have not been done.

Plant Cycling of N

Information on the N content of an entire citrus tree is meager. The size of the mature tree makes the destructive biomass sampling a difficult and costly task (111). In forest tree studies, where there is a commercial interest in the wood, biomass sampling procedures for the tree are more highly developed (9, 66, 91, 126). Also, with citrus, leaf N content is considered an adequate index of the N status of the tree. The commercial adoption of leaf analysis as a guide to fertilization of citrus has reportedly reduced N usage by about 50% in California (31).

A few studies on total citrus tree N content have been reported, but very often these studies were lacking in adequate replication (5, 63, 100, 121). In Florida, it was estimated that a 15-year-old orange tree absorbed only 25-30% of applied N (100). Of this amount, 33% is returned to the soil during the year through shedding of old leaves, flowers and young fruits, 50% is removed in the crop of fruit, and about 15% goes into permanent structures in the

form of new twigs and trunk enlargement. Data from a single 19-year-old grapefruit (<u>Citrus paradisi</u> Macf.) tree in Florida (5) indicated that the N content of component tree parts on a % dry weight basis in descending order was leaves, immature fruit, twigs less than 1.3 cm diameter, fibrous roots, large roots, limbs up to 1.3 cm diameter and trunk.

A series of studies to determine the N content of 'Valencia' orange trees have been reported from California (19,20, 121). One study showed that a 10-year-old tree contained 200 g of N in the leaves (19), while another study indicated that nearly one-half of the N content of the tree was in the leaves (20). Wallace <u>et al</u>. (121) reported that a 14-year-old 'Valencia' orange tree contained 673 g of N. The authors did not, however, indicate how much N was applied so that it is difficult to relate this figure to trees of similar age elsewhere. Apparently, a significant amount of N added to the soil is removed by citrus fruits (59, 131). Zidan and Wallace (131) reported that a mature 'Washington' navel orange fruit with a fresh weight of 192 g contained 394 mg of N while a 'Valencia' orange fruit of 165 g contained 327 mg.

<u>Residual Soil N</u>

A part of the N balance which is the most difficult to account for because of spatial variability is the amount of N remaining in the soil at any given sampling time.

Sampling and analysis of the soil material for NO_3^-N (1, 3, 51, 61, 81, 82) and/or total N (36, 84, 102) is commonly used to measure soil N content but large samples are usually required to achieve an acceptable degree of accuracy. The variation in residual soil N content, both within and among experimental units, has been reported to decrease with increasing depth in the soil profile (79). Also, the variability of virgin land has been reported to be less for N than similar areas of cultivated land (7).

In a Florida study involving an orchard of mature citrus trees, the soil nutrient content was the least variable in samples collected below the tree dripline as compared to other sampling locations (11). Nevertheless, it was demonstrated that a large number of samples was required to reduce the variation regardless of the sampling location.

Considerations for Increasing the Efficiency of N Usage by Citrus trees

General Concepts

Optimizing N use by citrus trees appears to involve the development of management programs which prevent the excessive loss of NO_3^- by leaching without sacrificing fruit yield, size, and quality (29). It has been suggested that optimum management could be achieved by applying only the amount of N needed to sustain high fruit production, with

leaf analysis being used as a guide to determine the proper rate (32, 90). Differences in citrus cultivar N requirements and soil types, however, dictate an approach in which timing, rate, placement, N source and water regime must be considered in the efficient use of fertilizer-N.

One approach to increasing the efficiency of N use has been to split the annual application of N (17, 35, 88). This is supported by a Florida experiment conducted under high rainfall conditions (35). In terms of citrus fruit productivity, however, other studies (17, 88) indicated that a single application of fertilizer-N applied during the drier portion of the year, in winter, gave the same yield response compared to 2 applications per year.

Another approach is the foliar application of N in the form of low-biuret urea. Studies from California (29, 30) indicated that foliar application of N was associated with lower NO_3^- leaching potential than was soil application. In general, foliar-applied N, under the low rainfall conditions of California, was found to be as effective as soil-applied N for fruit production (29, 30). This approach may not be suitable in Florida where frequent rains may wash away the N applied to the foliage. Efficient N use may require the application of nominal rates to the soil, supplementing this with foliar-applied N.

It has been suggested that in future studies, split soil application of N be a treatment along with foliar-soil combinations (54). A major limitation in foliar application

of N, however, is that it is energy intensive especially if frequent applications are necessary.

Concept of Controlled Release N Fertilizers and IBDU

The concept of the controlled release of N to increase fertilizer-N efficiency has been amply reviewed (62, 74, 76, 77, 85, 106). The basic approaches are the development of compounds of limited solubility, use of coated granules, and formulation of ammoniacal fertilizers with nitrification inhibitors. The objectives of such fertilizer-N forms are to minimize the immobilization, leaching and volatilization losses of soil-applied N, and to release an adequate amount of available N to satisfy the crop requirement. However, because of higher costs, these fertilizers are being used primarily in turfgrass, ornamentals, home grounds, nursery fields, and for other specialty situations.

Isobutylidene diurea is a condensation product of urea and iso-butyraldehyde patented in Japan as a slow-release N source. Hamamoto (41) described its preparation and physical properties in greater detail. His review of the studies conducted in Japan showed that the large granule of IBDU was effective in preventing high N leaching loss when applied to paddy soils. By using IBDU with green tea (*Camellia sinensis* [L.] Kuntze) plants Hamamoto (41) reported that one application was enough to get average yields and thus save labor. The conversion of IBDU to plant available form appears to result from the dissolution of IBDU

granules. The rate of dissolution is strongly influenced by particle size (41). Fine sized IBDU granules release larger amounts of N than coarse granules. This was observed in an incubation study (48), for turfgrasses (116, 117), and for flue-cured tobacco (*Nicotiana tabacum* L.) (71). Hughes (48) confirmed Hamamoto's (41) findings that IBDU-N release was greater at low pH values and high temperatures. In evaluating IBDU for 'Merion' Kentucky blue grass (*Poa pratensis* L.), Moberg *et al*. (72) indicated that a uniform growth response was possible from 2 applications of IBDU as compared to 3 of UREX (a urea-paraffin product). Studies in citrus or other tree crops with IBDU have not as yet been reported.

Analytical Procedures for N Balance Components

Leached N Sampling and Analysis

Soil N losses from leaching have generally been studied in lysimeter experiments or in controlled field drainage plots by measuring the N content of the effluent water (43). In citrus, lysimeter studies have largely been limited to young trees in the greenhouse. Such studies can provide useful basic information, but they are limited in scope because of the difficulty of extrapolating the data to orchard conditions (39). Moreover, a major shortcoming of lysimeters is the retention of more moisture than

corresponds with field capacity, resulting in the danger of anaerobiosis and denitrification (23).

In mature citrus orchards, several approaches have been made for estimating the leaching of fertilizer-N. Wander (123) analyzed water samples from the lower edges of citrus plantings located on slopes in Florida. Because the actual amount of water used by mature citrus trees and the exact rainfall in the local area was not known, however, it was difficult to translate such water analyses into figures representing actual amounts of N lost by drainage.

Various systems of drain lines and tiles have been devised in which data obtained by effluent water analysis and water discharge rates are used to calculate the amount of N leached. The amount of NO_3-N in the drainage from citrus groves has been determined by this procedure in California (26, 60) and Florida (16, 18). However, the reliability of this approach for monitoring subsurface NO_3-N losses has been questioned (108).

Several investigators have used porous ceramic cups to collect soil solution samples from citrus groves (10, 26, 35, 60). This procedure was found to be useful for estimating the potential for NO_3^- pollution in a Florida citrus grove (35). The procedure also gave a reasonable estimate of the amount of NO_3-N leached from a millet (<u>Pennisetum typhoides</u> L.) plot (37). However, this procedure has been

criticized because of the difficulty of providing enough water samples for chemical analysis and the requirement for a suction device. A new vacuum extractor was developed to surmount these difficulties but its usefulness has been limited by operational problems (27).

A new approach to calculating the leaching of NO_3^- from the root zone of crops is based on a comparison of the behavior of NO_3^- and Cl^- ions in the drainage or percolating waters that have moved below the root zone (82, 83). Changes in the ratio of these ions were used to calculate the amount of NO_3^- leached. In unsaturated soils where the determination of NO_3^- and Cl^- concentrations in the percolating water is difficult these concentrations were determined in a saturation extract. In both cases NO_3^- and Cl^- ratios were found to be satisfactory in estimating NO_3^- leached below the root zone of crops.

Residual Soil N Sampling and Analysis

Soil samples from citrus orchards are obtained using various sampling techniques. For cores greater than 6 m in length, a power-driven 45-cm diameter auger is often used (82). When samples are taken to only 6 m, a truck-mounted hydraulically powered sampler is frequently preferred. Most sampling in citrus orchards is conducted to shallower depths, generally not exceeding 4 or 5 m. In such cases, conventional sampling soil tubes or augers are used.

Several analytical procedures have been adopted to determine residual soil N. For total N determination, 2 methods have gained general acceptance: the Kjeldahl method which is essentially a wet-oxidation procedure, and the Dumas method which is fundamentally a dry-oxidation procedure (12). Residual soil N is also determined by analyzing the soil for exchangeable NH_4^+ and NO_3^- ions using steam distillation procedures (13). Recent trends in quantitating residual soil N, however, have involved the determination of NO_3^- (67) and NH_4^+ (4) ions in saturation extracts using specific ion activity electrodes.

Soil Water Measurement

Nitrogen is absorbed by plant roots from the soil solution. The soil water content is important, therefore, not only because of its function as a solvent but also because its mass movement is directly related to the leaching of the soil profile.

Soil water content is measured by several techniques, each with advantages and disadvantages. One technique used extensively in loam- to clay-textured soils is based upon the tensiometer (92, 93, 95, 105). The information furnished by tensiometers tends to be qualitative. Tensiometers are generally used for determining timing and duration of irrigation and have not been found to be particularly useful for sandy soils (52, 56).

Electrical-resistance blocks are not extensively used on sandy soils (64, 105) because gypsum blocks operate most reliably in the drier portion of the soil water content spectrum. In the sandy Florida soils, the available water is relatively small, and soil water should be maintained above 65% of field capacity. Under these conditions gypsum blocks are not particularly suitable.

For direct quantitative measurement of soil water by volume, 2 methods are used. The gravimetric procedure involves the calculation of a volumetric water content from the weight of the water in a soil sample and the soil bulk density (46, 64, 94). Rapid, large-scale soil water content sampling by this technique is laborious and time-consuming.

The neutron scattering method is a faster and equally accurate method as compared to the gravimetric procedure (14, 15, 40, 104). The method has been found to be useful in studying patterns of soil water depletion in Florida citrus groves (53).

Plant Tissue Sampling and Analysis

The leaf is the most commonly sampled tissue to determine the N status of a citrus tree (31, 32, 99, 101). As a result, techniques in leaf sampling and analytical procedures have been highly developed. The entire mature tree, however, is rarely sampled to determine its total N content.

One approach for determining the N content of the tree is to uproot the entire tree. The tree is then fractionated into various component parts and the N content of sample parts determined after oven-drying and grinding. This approach has been tried in Florida (5) and in California (19, 20). Another approach has involved making a periodic weight and chemical determination of all the blossoms, leaves and fruits that fall from citrus trees. Wallace *et al*. (121) used this approach to obtain data which were then combined with similar information for harvested fruits, new leaves and twigs, to obtain a measure of the nutrient content of the tree.

Isotope Approach to N Utilization by Citrus Trees

The use of isotopes in tree nutrition research was discussed by Walker (118) and Hauck (44). The advantages of this technique include the direct measurement of transport velocities and separation of newly absorbed nutrients from those already present in the various components of the ecosystem (96).

Nitrogen occurs in nature in 2 stable isotopes, N^{14} and N^{15}. Only recently has it been possible, as the result of advances in cryogenic techniques whereby nitric oxide gas is liquefied and then distilled, to separate the 2 isotopes with relative ease (21). Nitrogen^{15} fertilizer formulations are those which have been enriched with excess N^{15}

while N^{15}-depleted fertilizers, also known as N^{14} fertilizers, are those from which much N^{15} has been removed.

Studies using N^{15} as a tracer are commonplace in agronomic crops because the plants are relatively shallow-rooted (6, 49, 50, 73, 112, 127, 128, 130). Deeper-rooted forest and fruit trees do not lend themselves to N balance studies using N^{15} (66, 75). The high cost of the tracer has largely restricted its use to laboratory and greenhouse studies with young trees and strongly affected the size of the experiment and the experimental design. Furthermore, the procedure requires the use of expensive instrumentation to which many laboratories may not have access. Nevertheless, such studies have been reported for young apple (*Malus sylvestris* Mill.) trees (24, 38, 45) and nonbearing prune (*Prunus domestica* L.) trees (124).

Greenhouse studies with citrus using N^{15} were reported by Wallace (119, 120) and Wallace *et al*. (122). Wallace (119) found that growth complications and variability in plant material resulted in conventional methods being inferior to the isotopic technique in studying the influence of temperature on N absorption and translocation. His qualitative investigation (120) showed that NO_3-N was 2 to 5 times as readily absorbed from soil as was NH_4-N by 8-week-old cuttings of 'Eureka' lemon (*C. limon* L.). Nitrogen^{15} appeared in the leaves of a 3-year-old tree 4-7 days after application to the tree (122).

After this initial interest, no studies in citrus with N^{15} have been reported until recently. Kubota and coworkers (57, 58) investigated the behavior of N supplied in early spring and early summer on 9-year-old 'Satsuma' mandarin (*C. unshiu* Marcovitch) trees. In the spring experiment, N^{15} was detected in rootlets and leaves 3 and 7 days, respectively, after the application. Seventy-five percent of absorbed N^{15} was found in the aerial parts of the tree. In the summer study, N^{15} was detected in rootlets and spring leaves the next day after application, indicating a faster absorption of N in summer. Ninety-two percent of the N^{15} was distributed in the above ground parts. A review of N^{15} studies on citrus in Japan was recently presented by Yuda (129).

Both N^{15} depleted and N^{15} enriched fertilizer materials have been reported to give accurate and precise measurement of tracer N in plant tissue (28, 103). No studies with N^{15} depleted fertilizers, however, appear to have been reported with citrus.

MATERIALS AND METHODS

Experimental Site

Experiments for this study were conducted on an Astatula fine sand site 24 km from Lake Alfred, Florida. The soil is a Typic Quartzipsamment of the Entisols (47). Typically, it is well-drained with a low water and mineral nutrient retaining capacity.

Experimental Design

Experiment 1

Two factors, N source and irrigation, were examined in this experiment. Levels of the N source factor included no N control, IBDU-N, and NH_4NO_3-N, while those of the irrigation factor were no irrigation, low and high irrigations. It was desired to study these treatments in a factorial arrangement; however, it was not possible to physically establish the experiment in this manner because of the limitation imposed by the irrigation treatment. Therefore, the 1-year-old 'Pineapple' orange (*Citrus sinensis* [L.] Osbeck) trees on 'Alemow' (*C. macrophylla* Wester) rootstock were spaced at 3 x 3 m in 2 rows on July 13, 1978, using a modified split plot design (Fig. 1). The field layout consisted of 3 replications with irrigation level

Fig. 1. Planting plan and statistical design.

as the main plot treatment. The size of each main plot was determined by 6-m lengths of perforated sprinkler pipe used to apply the irrigation treatments. Each main plot, therefore, had 4 trees, 2 on each side of the pipe. Each single tree plot received one level of the N treatment but 4 replications of each N treatment were randomly distributed over the 3 irrigation main plots. Thirty-six trees were used in the experiment.

Fertilizer-N from IBDU and NH_4NO_3 sources at the rate of 201.6 g/tree was hand broadcast in a 3 x 3 area around each tree on September 28, 1978, 11 weeks after the trees were planted. Trees in control plots were not fertilized. Irrigation treatment was not started until November 27, 1978, after rainfall had tapered off. Soil water content was used to schedule irrigation. Approximately 0.75 cm of irrigation water was applied whenever the average soil water content fell below 4% by volume in the 0- to 60-cm soil profile of the high irrigation plots. The high irrigation plots were irrigated twice as often as the low irrigation plots which also received 0.75 cm of irrigation water on each application. A rain gauge at the experimental site and an irrigation flow-meter were used to monitor water supply. When the flow-meter malfunctioned 1500-ml cans were placed in the plots for collection and measurement of the amount of irrigation water delivered.

The experiment was terminated on January 9, 1979, because of freeze damage. Fertilizer-N and the first

irrigation had been applied 14 and 6 weeks, respectively, prior to the termination of the experiment. The trees under low irrigation had received a total of 2.20 cm of irrigation water in 3 irrigations while those under high irrigation had received 4.95 cm in 6 irrigations. For the entire period of the experiment, the nonirrigated plots had received 20.17 cm of rainfall; the low and high irrigation plots had received a combined total of 22.37 and 25.12 cm of rainfall and irrigation, respectively.

Experiment 2

This experiment was initiated to clarify certain results obtained in Experiment 1. The total N content of NH_4NO_3-fertilized trees was 42% higher than that of the IBDU-fertilized trees. Moveover, the complicating effect of the freeze damage on N absorption was not known. It was decided to determine if the same trend in N absorption would prevail during the warm spring weather.

Nine unused trees planted at the same time as those in Experiment 1 had been left unfertilized from the summer of 1978 through March, 1979. The 3 replications of single tree plots were arranged in a randomized complete block design, having as treatments unfertilized control, IBDU and NH_4NO_3 as N sources. No irrigation treatment was applied, however. Natural precipitation and routine

irrigation of the adjacent mature citrus grove provided the only water supply.

Data from Experiment 1 indicated that NH_4NO_3-fertilized trees had higher N content than IBDU-fertilized trees. The effect of the freeze damage on N absorption from the 2 N sources was not known. It was necessary therefore to establish if the same trend would be manifested in warm weather. Hence, the trees in Experiment 2 were deliberately grouped on the basis of their trunk diameter; IBDU was applied to the largest trees, and NH_4NO_3 to the smallest trees. Control trees were intermediate. The same rate of fertilizer-N in Experiment 1 was hand broadcast in a 3 x 3 m area around the tree on March 23, 1979. The experiment was terminated on May 8, 1979, 6 weeks after fertilizer application.

Experiment 3

Three 16-year-old 'Pineapple' orange trees in an existing rate and fertilizer-N source study were used for this experiment. The trees had been fertilized with the same rate of NH_4NO_3 since April 5, 1973, until September 23, 1977. In the current experiment, one of the trees received a total of 707.2 g of N per year, in 3 equal applications on March 2, 1978, June 11, 1978, and October 25, 1978, as IBDU. Another tree received the same rate of N as NH_4NO_3 on the same dates. The fertilizer was applied by hand broadcasting around the tree. Other nutrients were

adequately supplied to the fertilized trees. The third tree which did not receive any fertilizer-N at the specified dates was used in this experiment as the unfertilized control.

In order to study N movement in uncropped land 1 circular fallow plot 6 m in diameter, which corresponded to the tree canopy diameter, was fertilized with IBDU on October 25, 1978. Only one-third of the total annual application in the tree plots was used. Another similar plot was fertilized with the same rate of N as NH_4NO_3. A third plot was left unfertilized as a control. The 6 unreplicated plots in the experiment were subjected to the routine management of the adjacent grove. The experiment was terminated on February 17, 1979, 17 weeks after the fall application of fertilizer-N, at which time the plots had received 25.90 cm of rainfall and irrigation since October 25, 1978. Evapotranspiration for the duration of the study was estimated from climatological data (55).

Field Sampling Procedures

Soil Water Sampling

Changes in soil water content were measured with a Nuclear-Chicago neutron probe (P-19) and a scaler (53). One aluminum access tube for the probe was installed about 45 cm from every other tree in Experiments 1 and 2. In

Experiment 3, one tube was installed just inside the drip-line of each tree and at an equivalent distance from the center of each fallow plot.

One-minute readings were taken at depth increments of 15 cm, beginning at 15 cm. The readings were converted to % water content by volume using a calibration curve developed from previous sampling in the experimental area (53). The water content of the surface 15 cm was determined gravimetrically. A composite of duplicate 2.5 x 15 cm cores of soil per plot in the 3 experiments was collected and its gravimetric water content determined by over-drying to constant weight at 105°C. The water content was transformed to a volume percentage by multiplying the % weight by the average soil bulk density (1.54 g/cm^3). Water content in the soil profile was calculated by multiplying the average volume ratio by the depth of the entire profile and results expressed as cm of water.

Soil Sampling

A composite of duplicate 2.5-cm diameter soil core samples was taken within 30 cm from the tree from 0-7 cm and 7-15 cm, and thereafter at 15-cm increments down to 60 cm in Experiments 1 and 2. Soil samples were similarly taken at the tree canopy dripline down to 120 cm in Experiment 3. In Experiment 1, samples were taken when cumulative rainfall exceeded 1.25 cm. After the initiation of the irrigation treatment, samples were taken only at the

termination of the experiment. In Experiment 2, samples were taken after 2.28, 9.14 and 17.87 cm of cumulative rainfall and irrigation. Samples were taken following more than 4.87 cm of rainfall and/or irrigation in Experiment 3.

In order to prevent free movement of water from the soil surface through the sample holes, each hole was filled with white sand, obtained from elsewhere, and marked to avoid future sampling in that immediate vicinity.

Plant Tissue Sampling

Tree growth measurements in Experiments 1 and 2 were obtained by measuring the diameter of the trunks and the destructive sampling of the tree. Tree trunks were painted at a point 15 cm above the bud union and the initial and final trunk diameter recorded. Trees were excavated by digging a trench 60 cm from the tree and recovering the root system as much as practical. Each tree was fractionated in the laboratory into 7 components: fibrous and lateral roots, taproot, rootstock trunk, scion trunk, crotch branches, green twigs and leaves. The root system was rinsed in running tap water and the fresh and oven-dry weight (70°C) of each component obtained.

In the mature tree experiment, fruits were harvested on February 17, 1979, and the total fresh weight recorded. One 30-fruit sample from each tree was ground in a communiting machine, and 2 subsamples oven-dried at 70°C for dry weight determination and chemical analysis.

The number of leaves on each mature tree was estimated by the following procedure. Leaves in a 30 x 30 cm frame from 4 sides of the tree were stripped and the average number in the frame determined. The leaves were oven-dried for 48 hours at 70°C and the total dry weight determined. The total dry weight of the sampled leaves was used to calculate the average dry weight of a leaf. Tree height and tree width in 2 directions (north-south and east-west) were also measured. The canopy surface area was then calculated from the formula:

$$S = 2\pi W/3h^2[(W/16+h^2)^{1.5}-(W/4)^3]$$

where h = height and W = width of the tree (98). The number of leaves on a tree was then estimated from a knowledge of the canopy surface area.

Sample Preparation and Analysis

Soil Samples

All soil samples were air-dried and sieved through a 2 mm screen. Total soil N was determined by a semi-micro Kjeldahl procedure using a salicylic-sulfuric acid mixture (12). Soil samples from the 4 replications in Experiment 1 were combined for the determination of exchangeable NH_4^+ and NO_3^- by a steam-distillation procedure using Devarda alloy and MgO (13). Samples were not sufficient for the determination of these ions for the second sampling date

in Experiment 1 and for all samples in Experiments 2 and 3. Total N was expressed as % N on a dry weight basis and NH_4-N and NO_3-N as ppm. When a quantitative account for N was being made, these values were converted to g or kg of N in the soil profile. This was obtained as the product of area, depth, average bulk density (1.54 g/cm^3) and average N concentration in the profile.

In Experiments 1 and 2, the N content of the profile was calculated for the total area fertilized (90,000 cm^2) but since the root system of the young trees occupied an area less than 60 cm diameter, the N content was also calculated for the latter area (2828 cm^2). The depth used in the calculations was 60 cm. For the mature tree experiment, the area and depth were 28.28 m^2 and 1.20 m, respectively. The recovery of fertilizer-N was obtained by subtracting the total soil profile N content of the unfertilized plot from that of the fertilized plot. This value was expressed as the percentage of the amount of N applied.

Plant Tissue Samples

All plant parts were ground in a Wiley Mill and passed through a 20-mesh screen. Total N was determined by a semi-micro Kjeldahl procedure using 0.5 g subsamples (12). Nitrogen values were expressed both as % of dry weight and in absolute amounts. The latter were obtained by multiplying % N by the total dry weight of the component part. The recovery of fertilizer-N by the trees was obtained by

subtracting the total N content of the unfertilized tree from that of the fertilized tree and the result expressed as the percentage of the amount of N applied. In the mature tree experiment, the N content of fruits and leaves from the unfertilized tree was similarly substracted from those of the fertilized tree.

Statistical Analysis

In Experiments 1 and 2, data pertaining to tree growth, tissue N content, and soil total N content were submitted to analysis of variance. In Experiment 1, these data were analyzed in a 3 x 3 factorial arrangement. Data for Experiment 2 were treated as a randomized complete block design. Significant differences were determined by Duncan's multiple range test. Soil water data and those from the mature tree experiment were not analyzed.

RESULTS AND DISCUSSION

Experiments 1 and 2

Preliminary Remarks

Experiment 1 was prematurely terminated 14 weeks after fertilizer application and 6 weeks following the first irrigation because the trees were beginning to show the effects of freeze damage. This was especially apparent in the unfertilized control trees where extensive leaf drop occurred. Since the complicating effect of the freeze damage on N absorption was not known, and NH_4NO_3-fertilized trees appeared to have higher N content in comparison to IBDU-fertilized trees, Experiment 2 was started to determine if the same trend would prevail in warm weather. Therefore, the trees in Experiment 2 were deliberately grouped such that IBDU-fertilized trees were larger in trunk diameter than control and NH_4NO_3-fertilized trees (Table 1).

Tree Growth Analysis

The young trees in both experiments generally showed vigorous growth regardless of treatment. Trees fertilized with NH_4NO_3 and IBDU had denser canopies than the unfertilized control trees, and those fertilized with NH_4NO_3

Table 1. Effect of N source on the dry wt and growth of several tree component parts.[z]

Expt.	N source	Root system dry wt	Top dry wt	Total dry wt	Initial trunk diam (cm)	Final trunk diam (cm)	% trunk diam increase
		g					
1	Control	80.6ns	107.5ns	188.1ns	1.31ns	1.34ns	2.3ns
	IBDU-N	86.1	129.1	215.2	1.42	1.47	3.6
	NH_4NO_3-N	99.2	134.3	233.5	1.41	1.46	3.5
2	Control	36.4b	50.2b	86.6b	0.88b	0.92b	4.6ns
	IBDU-N	44.2a	66.8a	111.0a	1.03a	1.10a	6.8
	NH_4NO_3-N	26.0b	44.7b	70.7b	0.78b	0.83b	6.4

[z]Mean separation within column for each experiment by Duncan's multiple range test, 5% level; ns = not significant.

had darker foliage than IBDU-fertilized trees. Leaves from the control trees in Experiment 1 were dull green and began to shed toward the end of the study, indicating that N was becoming a limiting factor (22) and the trees were responding to the cold weather. Leaves from the control trees in Experiment 2 were also dull green, but they did not shed.

Ammonium nitrate and IBDU appeared to increase the dry matter content of nearly all tree component parts as compared to the control in Experiment 1 (Table 2). A difference in dry matter content was particularly apparent in the leaves collected from both of the fertilizer-N treatments which were statistically greater than the control. The NH_4NO_3-fertilized trees showed numerically greater dry weight values compared to the IBDU treatment in the more succulent components of the tree, but they were not statistically different.

It is not plausible to compare the effect of N sources on the growth of the tree parts in Experiment 2, because of the initial tree size differences. Nevertheless, there were differences (nonstatistical) particularly in green twig dry weight indicating a greater response to NH_4NO_3 fertilization as compared to the other treatments (Table 2). Trees fertilized with NH_4NO_3 were the smallest and yet had numerically greater green twig dry weight than the rest. This trend was similar to the one in Experiment 1. Significant differences between treatments in fibrous

Table 2. Effect of N source on tree component part dry wt.[z]

Expt.	N source	Fibrous and lateral roots	Taproot	Rootstock trunk	Scion trunk	Crotch branches	Green twigs	Leaves
		g						
	Control	51.4ns	29.8ns	29.1ns	36.3ns	13.6ns	9.8ns	18.2b
1	IBDU-N	59.6	26.6	29.6	41.1	15.9	13.4	29.2a
	NH_4NO_3-N	60.9	38.3	29.8	36.3	20.8	15.9	31.4a
	Control	24.9ab	11.5ns	16.3ns	15.3a	5.1ns	6.0ns	7.5b
2	IBDU-N	29.8a	14.4	16.3	15.4a	7.5	8.0	19.5a
	NH_4NO_3-N	16.5b	9.5	11.3	8.1b	4.1	8.1	13.1ab

[z]Mean separation within column for each experiment by Duncan's multiple range test, 5% level; ns = not significant.

and lateral roots, and the scion trunk in Experiment 2, but not in Experiment 1, showed that these differences were a reflection of the initial tree size differences in Experiment 2 rather than treatment effects.

Irrigation level did not statistically influence the distribution of dry matter or the N content of the various tree fractions in Experiment 1 (Table 3). There were no significant interactions between N source and irrigation level. Data related to irrigation level effects, except for those in Table 3, have been omitted from this study because irrigation level effects were not statistically different and there were no irrigation level x N source interactions.

The dry weight of the total root system and the aboveground parts of the tree in Experiment 1 were consistently highest for the NH_4NO_3 treatment (Table 1), followed by the IBDU and control treatments; however, the data did not show any statistical differences. Nitrogen source also had no statistically significant effect on total tree dry weight or % trunk diameter increase. Nevertheless, N fertilization resulted in larger % trunk diameter increase over the control trees in both Experiments 1 and 2 (Table 1). Trunk growth was greater in Experiment 2 than in Experiment 1 presumably because of the beneficial effect of the warm spring weather on tree growth. Total tree dry weight in Experiment 2 did not appear to have been altered by

Table 3. Effect of irrigation level on the N content and dry wt of tree components.[z]

Irrigation level	Fibrous and lateral roots	Taproot	Rootstock trunk	Scion trunk	Crotch branches	Green twigs	Leaves
	Dry wt, g						
None	52.7ns	30.5ns	30.3ns	39.2ns	17.3ns	11.0ns	25.8ns
Low	61.4	31.1	28.0	37.9	16.1	13.1	24.3
High	57.7	32.6	30.1	37.6	16.9	15.0	28.7
	N concn, % dry wt						
None	1.70ns	0.88ns	0.70ns	0.68ns	0.79ns	1.55ns	3.03ns
Low	1.50	0.77	0.62	0.60	0.77	1.38	3.03
High	1.54	0.79	0.63	0.67	0.74	1.34	3.01

[z]ns = not significant.

treatments presumably due to the short duration of the experiment. It reflected the trend in the initial trunk diameter measurements (Table 1).

Irrigation level had no statistically significant effect on the dry weight of the root or shoot system of the trees in Experiment 1, or the dry weight and the % trunk diameter increase of the tree. There was, however, a tendency towards greater trunk growth with an increase in irrigation level. Koo (55) reported a similar trend for mature citrus trees in Florida.

Several factors may have contributed to the absence of an irrigation effect in Experiment 1. These would have included duration of the experiment, the quantity and frequency of irrigation as well as the time of year. The trees were irrigated only during the last 6 weeks of the experiment. It is possible that irrigated trees did not have enough time to respond to the irrigation treatments. Furthermore, it has been shown in Florida that extra water applied to mature citrus trees between June and December, the approximate period of this study, did not contribute substantially to tree growth (55).

The lack of significant N source effects on tree growth in Experiment 1 can possibly be attributed to a diminished growth rate in winter (25). Also, the 14 weeks of experimentation probably were not long enough for the treatments to show their maximum effects on tree growth.

Patten and Domoto (78) and Miller (70) recently showed that N treatments had no significant effect on apple tree growth during the first growing season.

In Experiment 1, N source statistically altered the pattern of dry matter distribution (Table 4). A greater proportion of the total dry weight was located in the taproot of the NH_4NO_3-fertilized and control trees as compared to the IBDU-treated trees. Both NH_4NO_3- and IBDU-fertilized trees had statistically greater proportion of their dry weight distributed in the crotch branches in comparison to control trees. The % dry weight of the scion trunk of the NH_4NO_3-treated trees was less than that of either the control or the IBDU-treated trees. The fact that the dry weight distribution was similar to the actual dry weight of certain tree parts (Table 2) makes it doubtful that all of these were true treatment differences. Moreover, treatment means in dry weight were not statistically different except for the leaves. Some of the significant treatment differences may very well be a reflection of initial differences in the trees. Nevertheless, there was a trend for NH_4NO_3-treated trees to have a greater dry matter in crotch branches, green twigs and leaves in comparison to IBDU-fertilized and control trees. As was the case with the dry weight of the tree fractions, irrigation level did not significantly affect the distribution of dry matter.

Table 4. Effect of N source on tree dry wt distribution.[z]

Expt.	N source	Fibrous and lateral roots	Taproot	Rootstock trunk	Scion trunk	Crotch branches	Green twigs	Leaves
		% total tree dry wt						
	Control	26.86ns	15.54A	15.54a	19.19A	6.85b	5.20ns	10.46ns
1	IBDU-N	27.32	12.27B	13.86ab	19.47A	7.36ab	6.06	13.60
	NH_4NO_3-N	25.92	16.51A	12.83b	15.81B	8.70a	6.74	13.61
	Control	28.71ns	13.28ns	18.78a	17.71a	5.92ns	6.88b	8.66b
2	IBDU-N	27.26	12.97	14.71b	13.87b	6.78	7.17b	17.59a
	NH_4NO_3-N	23.29	13.48	16.03b	11.40b	5.74	11.40a	18.58a

[z]Mean separation within column for each experiment by Duncan's multiple range text, 1% (capital letters) and 5% (lower case letters) level; ns = not significant.

The distribution of dry weight was similar in Experiments 1 and 2 (Table 4). In Experiment 2, the control trees had proportionally more of their dry weight in the rootstock and scion trunks as compared to the fertilized trees. The % dry weight in the green twigs of the control trees was, however, significantly less than in the NH_4NO_3-treated trees; but the greatest difference was in the leaf fraction. The % dry matter in the leaves of the fertilized trees was about twice as much as in the unfertilized control trees. Furthermore, the leaves of the fertilized trees in Experiment 2 represented a higher % of the total than in Experiment 1. This is a reasonable expectation because of the stronger growth flush in the spring than in the fall-winter.

Tree N Content and Distribution

The main effects of the N sources in Experiment 1 showed that the N concentrations were highly significantly different in all component parts of the tree, with NH_4NO_3-treated trees having the highest values followed by the IBDU-treated and control trees (Table 5). Nitrogen concentration was generally highest in leaves followed by fibrous and lateral roots, green twigs, taproot, crotch branches, rootstock trunk, and scion trunk. This order is similar to the data of Barnette *et al*. (5) for a mature tree of a different cultivar. Furthermore, the N concentrations in the current study were higher than the

Table 5. Effect of N source on N concn of tree component parts.[z]

Expt.	N source	Fibrous and lateral roots	Taproot	Rootstock trunk	Scion trunk	Crotch branches	Green twigs	Leaves
		% dry wt						
1	Control	0.81C	0.39C	0.37C	0.39C	0.48C	0.77C	2.31C
	IBDU-N	1.65B	0.84B	0.64B	0.66B	0.74B	1.58B	3.01B
	NH_4NO_3-N	2.29A	1.20A	0.93A	0.88A	1.07A	1.92A	3.75A
2	Control	0.83C	0.40C	0.47c	0.54c	0.49C	0.72C	2.04C
	IBDU-N	1.37B	0.67B	0.58b	0.65b	0.66B	1.38B	3.72B
	NH_4NO_3-N	2.45A	1.37A	1.00a	0.98a	1.25A	2.18A	5.18A

[z]Mean separation within column for each experiment by Duncan's multiple range test, 1% (capital letters) and 5% (lower case letters) level.

values reported by Barnette et al. (5). Such differences are not unusual when a young, vigorously growing tree is compared to a mature, fruiting tree (99). Also, the rate of N application in the current study was higher.

No significant differences due to irrigation level were detected in the N concentration of the various tree components (Table 3).

The results obtained in Experiment 2 were consistent with those in Experiment 1 in that the order of N concentration in all tree parts was NH_4NO_3- > IBDU-N > control (Table 5). Except for rootstock and scion trunks, these values were significantly different from one another at the 1% level. The N concentration for all tree parts was higher in the NH_4NO_3-treated trees than in their counterparts in Experiment 1, particularly in the leaves, fibrous and lateral roots, and in the taproot. It would not be unreasonable to assume that these relatively higher concentrations were partly a consequence of concentration effects, in view of the smaller trees assigned to the NH_4NO_3 treatment. Also, the higher soil temperature in the spring could have been conducive to more N absorption by the trees.

The total amount of N in a tree part, the product of the dry weight of that part and the N concentration on a dry weight basis, was not statistically affected by irrigation level in Experiment 1. There was, however, a statistically significant relationship between N source and

total N content of tree parts (Table 6). Numerically, the trend was similar to the N concentration in that NH_4NO_3-fertilized trees had the highest values followed by IBDU-fertilized and control trees. The data were, however, less consistent statistically.

The N content of the tree parts was reflected in the total amount of N in the tree (Fig. 2). Differences due to N source were highly significant with NH_4NO_3-treated trees containing about 3 and 1.5 times greater total N than the control and IBDU-treated trees, respectively. No statistically significant differences were detected due to irrigation level.

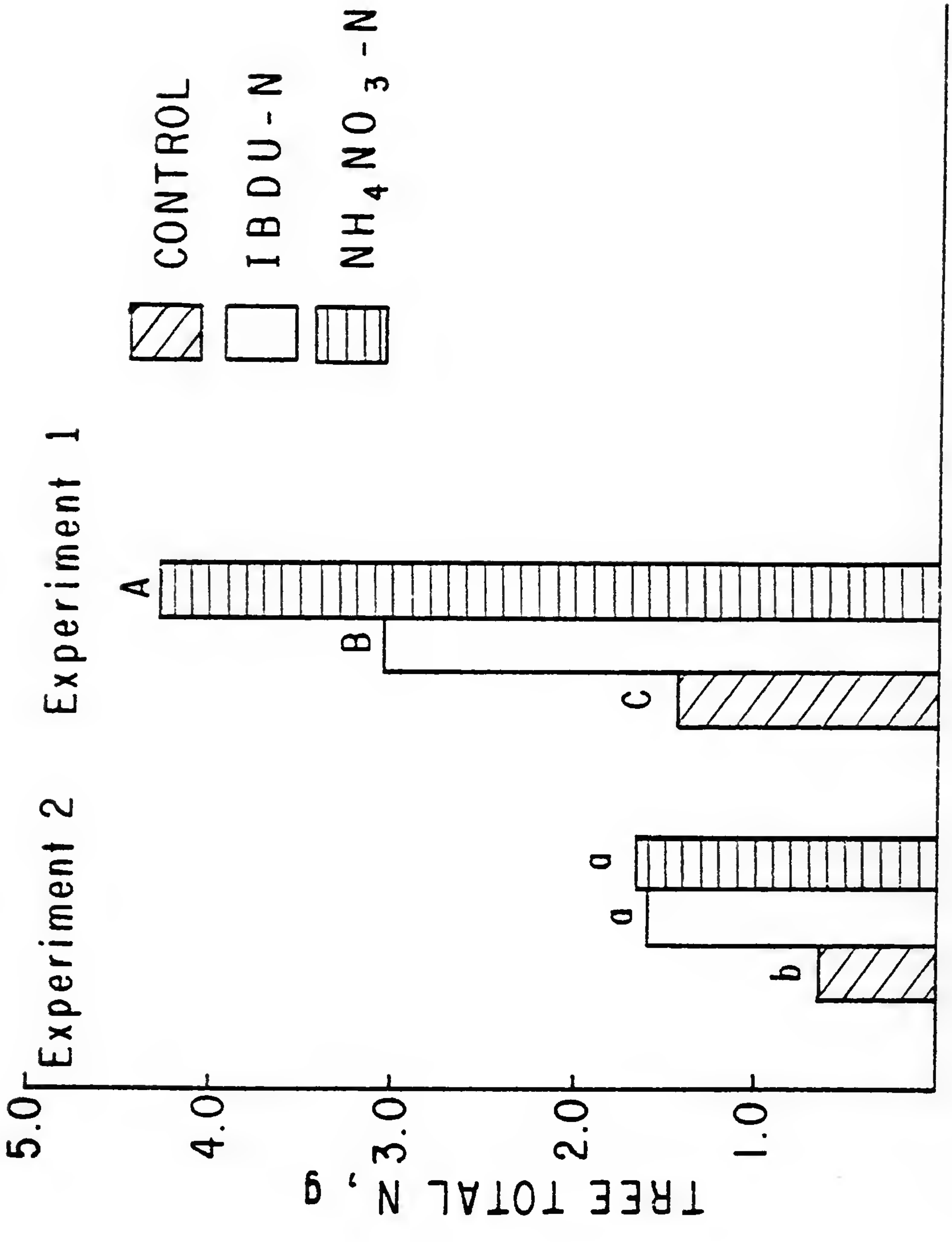
In Experiment 2, the total amount of N in each tree part (Table 6) and consequently in the entire tree (Fig. 2) was lower than in Experiment 1 probably because of the smaller trees used in Experiment 2. No meaningful importance can be attached to the statistical differences in Experiment 2 in the total N content because of the inequality of tree sizes. Despite the fact that the trees selected for the IBDU treatment were larger and had 1.6 times the dry weight of the NH_4NO_3-treated trees, total N in the NH_4NO_3-fertilized trees was 1.05 times that of the IBDU-fertilized trees. Equivalent biomass, including the root system, would absorb more N from NH_4NO_3 than it would from IBDU in a short period as in Experiment 1.

Table 6. Effect of N source on total N content of tree component parts.[z]

Expt.	N source	Fibrous and lateral roots	Taproot	Rootstock trunk	Scion trunk	Crotch branches	Green twigs	Leaves
		g						
1	Control	0.445B	0.115B	0.108B	0.140B	0.066B	0.078B	0.468B
	IBDU-N	1.044AB	0.222B	0.193A	0.270A	0.123B	0.209A	0.954A
	NH_4NO_3-N	1.488A	0.461A	0.270A	0.315A	0.221A	0.302A	1.277A
2	Control	0.225B	0.046ns	0.077ns	0.083ns	0.025ns	0.043C	0.154b
	IBDU-N	0.431A	0.096	0.094	0.101	0.050	0.110B	0.719a
	NH_4NO_3-N	0.451A	0.130	0.113	0.079	0.050	0.176A	0.690a

[z]Mean separation within column for each experiment by Duncan's multiple range test, 1% (capital letters) and 5% (lower case letters) level; ns = not significant.

Fig. 2. Relationship between N source and total tree N content. Mean separation by Duncan's multiple range test 1% (capital letters) and 5% (lower case letters).



TREE TOTAL N, g
5.0
4.0
3.0
2.0
1.0
Experiment 2
Experiment 1
b
a
a
C
B
A
CONTROL
IBDU-N
NH_4NO_3-N

There was no significant relationship between the distribution of N in the various tree parts and irrigation level in Experiment 1. Nitrogen source significantly affected the distribution of N in the taproot and scion trunk (Table 7). Regardless of N source, 30-34% of total tree N was located in fibrous and lateral roots. Leaves represented only 10-13% of the total dry matter of the tree but contained 30-33% of the total N in the tree. These figures correspond to those reported in earlier work for mature citrus trees (20, 63). Sixty, 57, and 55% of the total N in the tree were found in the aerial parts of the control, IBDU- and NH_4NO_3-fertilized trees, respectively. This may suggest that the more readily available the N source, resulting in luxury consumption, the greater the proportion of N stored in the root system (86).

As in Experiment 1, N source significantly affected the distribution of N in Experiment 2 (Table 7). Compared to Experiment 1, however, the proportion of N was greater in leaves and less in the fibrous and lateral roots of the fertilized trees than the control. The proportion of N in the taproot of NH_4NO_3-fertilized trees was higher than for IBDU-fertilized and control trees in both experiments. Whether it is a characteristic of citrus trees to accumulate NH_4NO_3-N in the taproot or some factor related to the time of sampling needs further investigation. In contrast to the data in Experiment 1, 57, 67 and 66% of the total N

Table 7. Effect of N source on N distribution.[z]

Expt.	N source	Fibrous and lateral roots	Taproot	Rootstock trunk	Scion trunk	Crotch branches	Green twigs	Leaves
		----------	----------	----------	% total tree N	----------	----------	----------
	Control	30.89ns	8.07b	7.53ns	9.79a	4.39ns	5.49ns	33.81ns
1	IBDU-N	34.07	7.56b	6.46	9.63a	4.03	6.81	31.24
	NH_4NO_3-N	33.37	10.69a	6.45	7.58b	5.04	6.89	29.92
	Control	34.96a	7.15ns	11.97a	12.90a	3.88ns	6.68b	23.95B
2	IBDU-N	26.92b	5.99	5.87b	6.30b	3.12	6.87b	44.90A
	NH_4NO_3-N	26.08b	7.69	6.69b	4.67b	2.96	10.42a	40.85A

[z]Mean separation within column for each experiment by Duncan's multiple range test, 1% (capital letters) and 5% (lower case letters) level; ns = not significant.

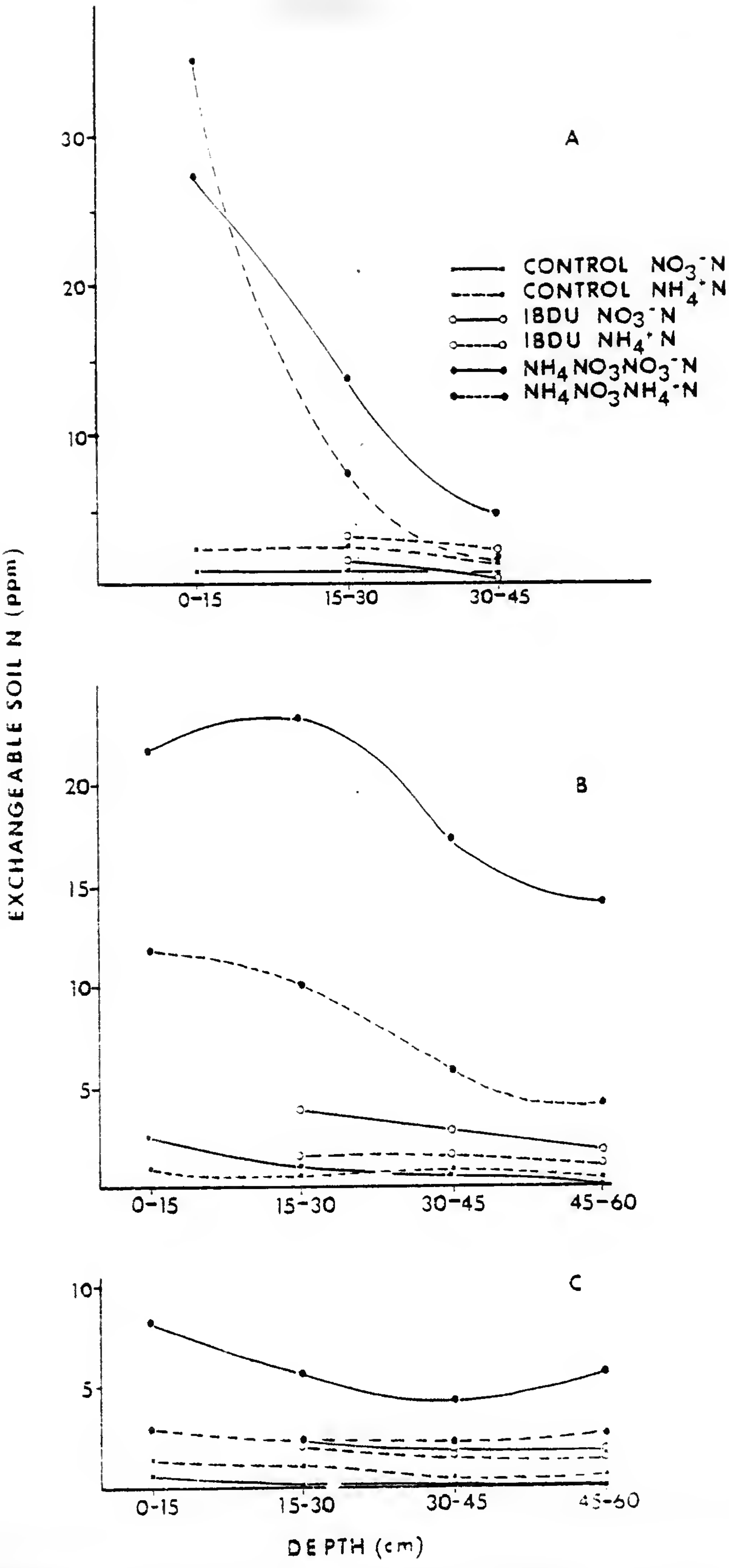
in the tree were found in the aerial parts of control, IBDU- and NH_4NO_3-treated trees, respectively. The greater proportion of total N in the aerial parts of the fertilized trees in the spring than in the fall-winter may reflect the more vigorous growth activity in the spring. Also, translocation of N from roots may be greater in the spring. The difference probably resulted from a lower activity of the nitrate reducing enzyme system during periods of low soil temperature in the winter (38).

Soil Profile Content and Distribution of N

Soil samples in Experiment 1 were taken to the 45-cm depth after 1.42 and 2.26 cm of cumulative rainfall on October 3 and October 19, 1978, respectively. Analysis of the first set of samples indicated that NO_3-N from NH_4NO_3 had moved to this zone (Fig. 3-A). As a result the sampling depth was extended to 60 cm. A third set of samples was collected after 4.87 cm of cumulative rainfall on October 31, 1978. After the initiation of the irrigation treatments, a fourth set of soil samples was obtained on January 9, 1979.

At the first sampling (Fig. 3-A), there was evidence that some NO_3-N from NH_4NO_3 had moved down to the 45-cm depth while NH_4-N from the same source had only moved to the 30-cm depth. A greater proportion of the NH_4-N was still retained in the 0- to 15-cm zone. Only a small amount of NH_4-N from IBDU had moved to the 30 cm depth

Fig. 3. Effect of N source on the exchangeable NH_4^+ and NO_3^- soil content. A, B, and C correspond to the 1st, 3rd and final soil sampling dates on October 3, October 31, 1978, and January 9, 1979, respectively. (Expt. 1).

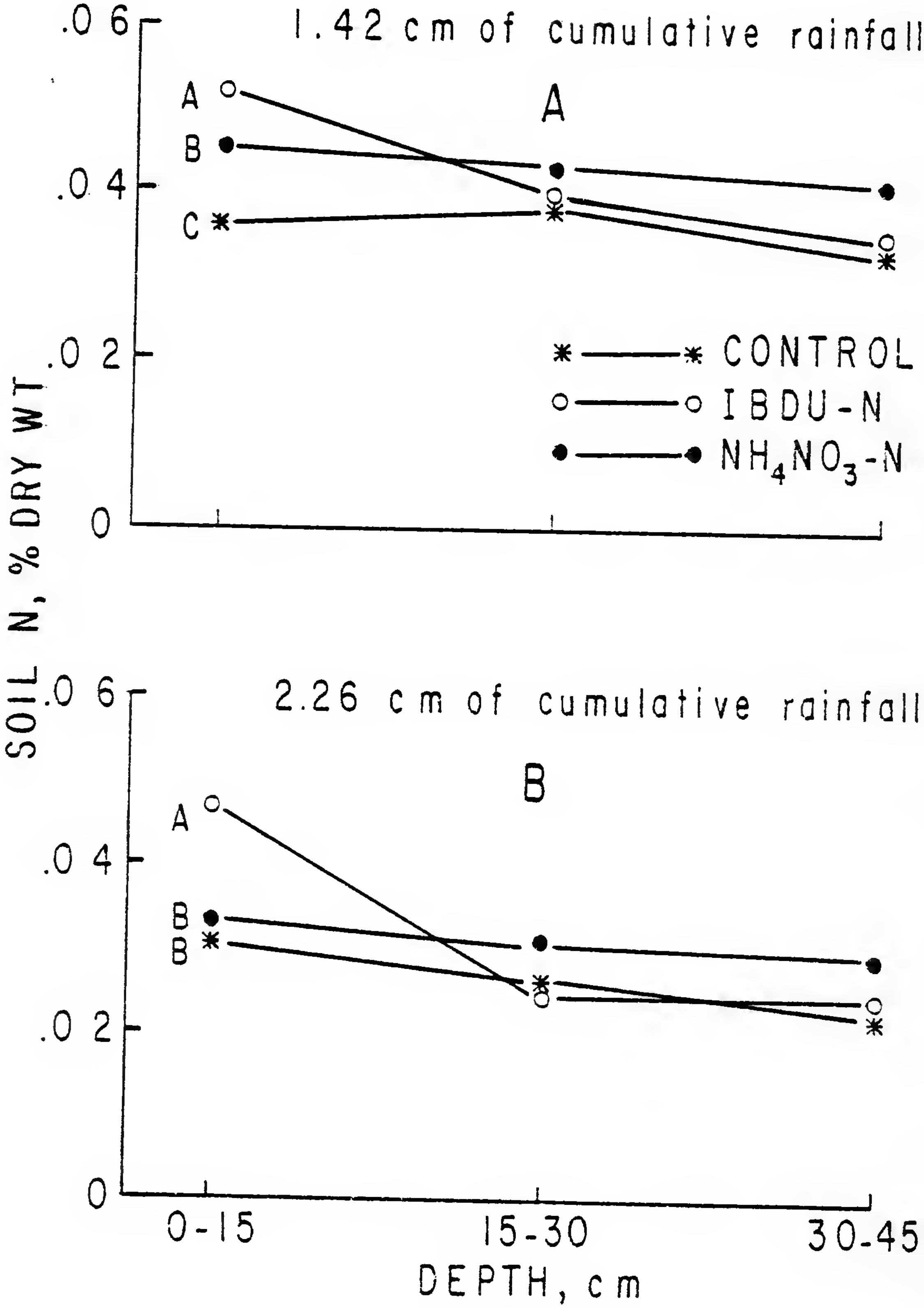

A
B
C
CONTROL NO_3^-N
CONTROL NH_4^+N
IBDU NO_3^-N
IBDU NH_4^+N
NH_4NO_3 NO_3^-N
NH_4NO_3 NH_4^+N
EXCHANGEABLE SOIL N (ppm)
DEPTH (cm)
0-15
15-30
30-45
45-60
30
20
15
10
5

presumably because of the sparingly soluble nature of IBDU which remained in the surface soil. Eighty-five percent of the applied N from NH_4NO_3 was accounted for in the 0- to 45-cm depth at the first sampling. The difficulty of extracting IBDU with 1 N KCl precluded the determination of NH_4^+ and NO_3^- in the 0- to 15-cm depth. The total N procedure, however, indicated that 94% of the applied N from IBDU remained in the 0- to 45-cm depth at the first sampling.

These trends in inorganic N concentrations were also revealed in the soil total N content in that values for the fertilized plots were higher than those for the control plots (Fig. 4-A). Soil samples were not sufficient for the determination of exchangeable NH_4^+ and NO_3^- at the second sampling. Nevertheless, there was an indication that N from NH_4NO_3 had probably moved past the 45-cm depth (Fig. 4-A).

At the third sampling it was apparent that NH_4-N and NO_3-N from NH_4NO_3 had leached down to the 45- to 60-cm depth (Fig. 3-B). This suggests that at least a part of the downward movement involved the un-ionized NH_4NO_3 fertilizer. The well-drained nature of Astatula fine sand, and its low organic matter content could have been factors contributing to this movement. Some NH_4-N and NO_3-N from IBDU had also moved down to the 60-cm zone, but on a smaller scale relative to NH_4NO_3. Ninety-one percent of

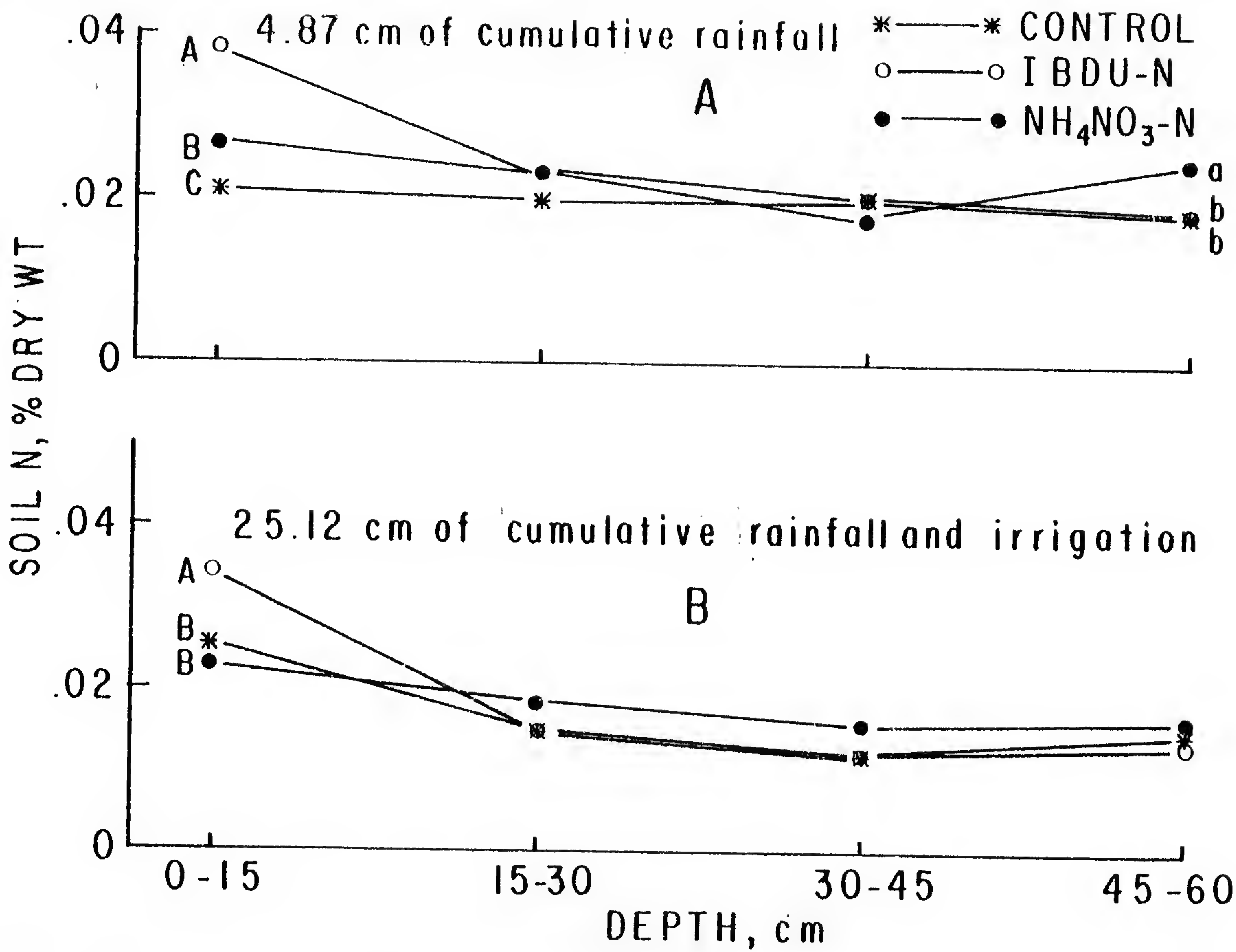
Fig. 4. Effect of N source on soil total N at the 1st (A) and 2nd (B) sampling dates on October 3 and October 19, 1978, respectively. Mean separation within depth by Duncan's multiple range test, 1%. (Expt. 1).


1.42 cm of cumulative rainfall
A
.06
.04
.02
0
A
B
C
CONTROL
IBDU-N
NH_4NO_3-N
SOIL N, % DRY WT.
2.26 cm of cumulative rainfall
B
.06
.04
.02
0
A
B
B
0-15
15-30
30-45
DEPTH, cm

the applied N from IBDU remained in the 0- to 60-cm depth at the third sampling; 82% of the NH_4NO_3-N could be accounted for in the same zone. Data for soil total N (Fig. 5-A), although less consistent in the 15- to 45-cm depth than those for exchangeable NH_4^+ and NO_3^-, supported the trend in the downward movement of N from both fertilizer sources.

The final soil sampling was completed 14 weeks after the trees were fertilized. Much of the N from NH_4NO_3 had been depleted from the soil profile (Fig. 3-C). Only 30% of the applied N from this source remained in the 0- to 60-cm zone. A part of the depletion could be attributed to root absorption. Soil water contents (Table 9) were generally below the maximum water storage capacity; however, rainfall events of 5.0, 1.3 and 2.6 cm on December 28, December 29, 1978, and January 3, 1979, respectively, suggest that leaching of some NH_4NO_3-N may have occurred beyond the 60-cm depth. Furthermore, provisions were not made in this study for the determination of gaseous losses of N which may have also occurred. As in the previous samplings the concentrations of exchangeable NH_4^+ and NO_3^- from IBDU in the 15- to 60-cm depth were lower than those from NH_4NO_3 (Fig. 3-C). There was also no indication of IBDU-N having been leached beyond the 60-cm depth since 66% of the applied N could be accounted for within this depth. In comparison to the other N sources, a greater proportion of the IBDU-N was retained in the surface soil (Fig. 5-B).

Fig. 5. Effect of N source on soil total N at the 3rd (A) and 4th (B) sampling dates on October 31, 1978, and January 9, 1979, respectively. Mean separation within depth by Duncan's multiple range test, 1% (capital letters) and 5% (lower case letters). (Expt. 1).



4.87 cm of cumulative rainfall
A
CONTROL
I BDU-N
NH_4NO_3-N
.04
.02
0
A
B
C
a
b
b
25.12 cm of cumulative rainfall and irrigation
B
A
B
B
SOIL N, % DRY WT
0-15
15-30
30-45
45-60
DEPTH, cm

Table 8. Quantitative estimates of evaporation and evapotranspiration from mature tree plots.

Period	Rainfall & irrigation, cm	Class "A" pan evaporation cm/day	Evapotranspiration cm/day	Potential net leaching, cm H_2O^z
Oct. 25-Nov. 9, 1978	4.87	0.39	0.22	+1.35
Nov. 9-Dec. 12, 1978	2.63	0.32	0.23	-4.96
Dec. 12, 1978-Feb. 17, 1979	18.40	0.27	0.13	+9.69

^{z}Excess water (+) and deficit (-) to effect percolation.

Table 9. Soil water content of young tree plots 24 hr. after a rainfall or irrigation event.

Sampling date	Cumulative rainfall and irrigation, cm	Soil water (0-60cm), cm	Field capacity (0-60cm),cm
Oct. 3, 1978	1.42	3.91	4.18
Oct. 19, 1978	2.26	3.47	4.18
Oct. 31, 1978	4.87	3.77	4.18
Jan. 9, 1979	25.12	4.00	4.18

In Experiment 2, sets of soil samples were taken 3 times on April 2, April 27 and May 4, 1979, following 2.28, 9.14 and 17.87 cm, respectively, of cumulative rainfall and irrigation. These samples were not sufficient for the determination of exchangeable NH_4^+ and NO_3^-. Soil total N concentrations in this experiment were higher than those from Experiment 1 (Figs. 6-8). Contamination from the regular fall (1978) and spring (1979) fertilization of adjacent mature trees may have contributed to the higher soil values in Experiment 2 as compared to Experiment 1. As in Experiment 1, however, there was a trend towards decreased soil N content with increasing cumulative rainfall and irrigation (Figs. 6-8).

At the first sampling there was an indication of some NH_4NO_3-N having moved to the 60-cm depth (Fig. 6), while only a small amount of IBDU-N may have moved to the 30-cm depth. Some N from IBDU appeared to have reached to the 45-cm depth as indicated by the bulge at the second sampling (Fig. 7), but the data from Experiment 1 (Fig. 3B-C) suggest that this could be a sampling error or error inherent in the soil total N procedure. As in Experiment 1, a higher proportion of the N from IBDU, relative to the other sources, was still retained at the surface soil at the last sampling (Fig. 8).

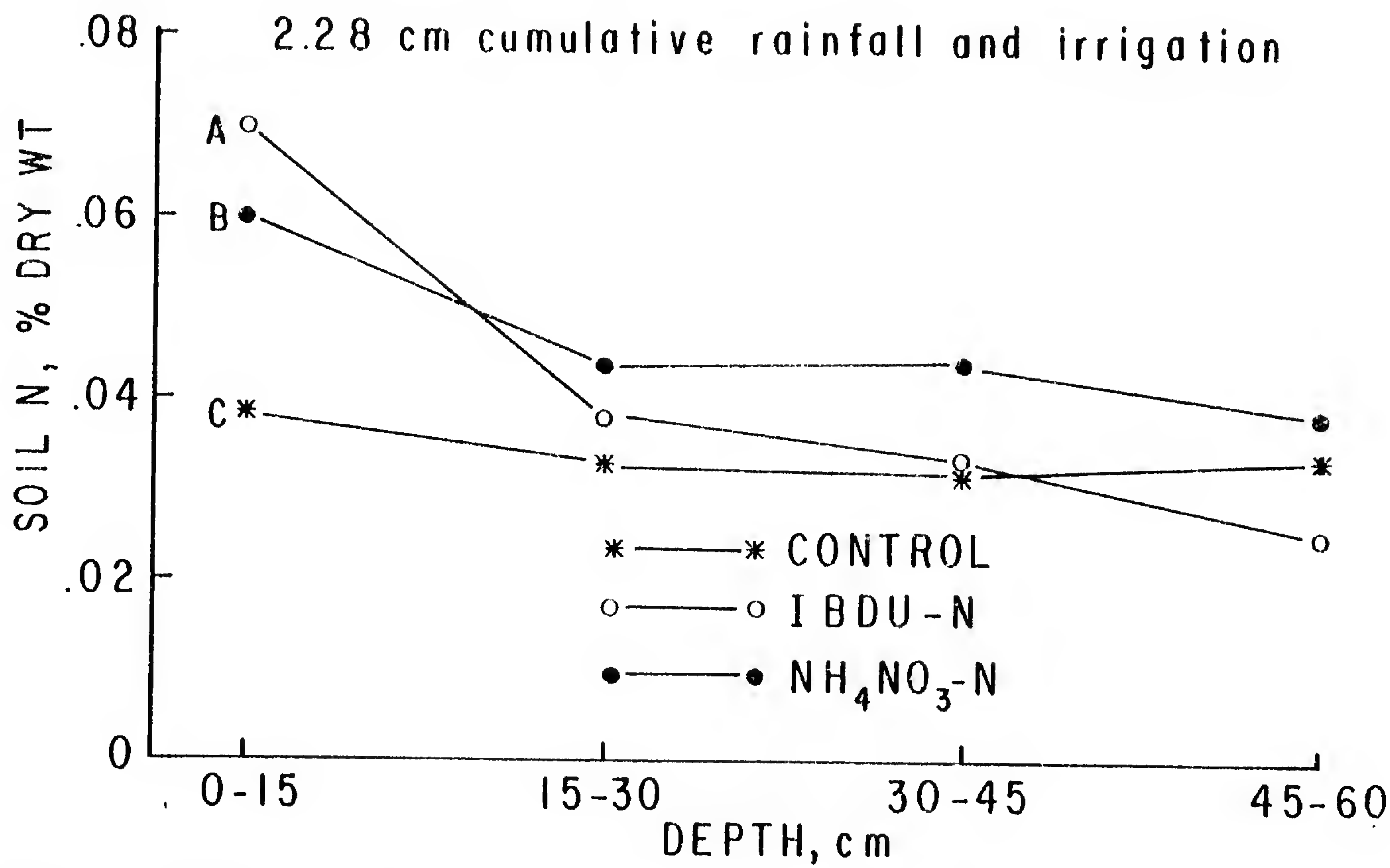


Fig. 6. Effect of N source on total soil N at the 1st sampling on April 2, 1979. Mean separation by Duncan's multiple range test, 1%. (Expt. 2).

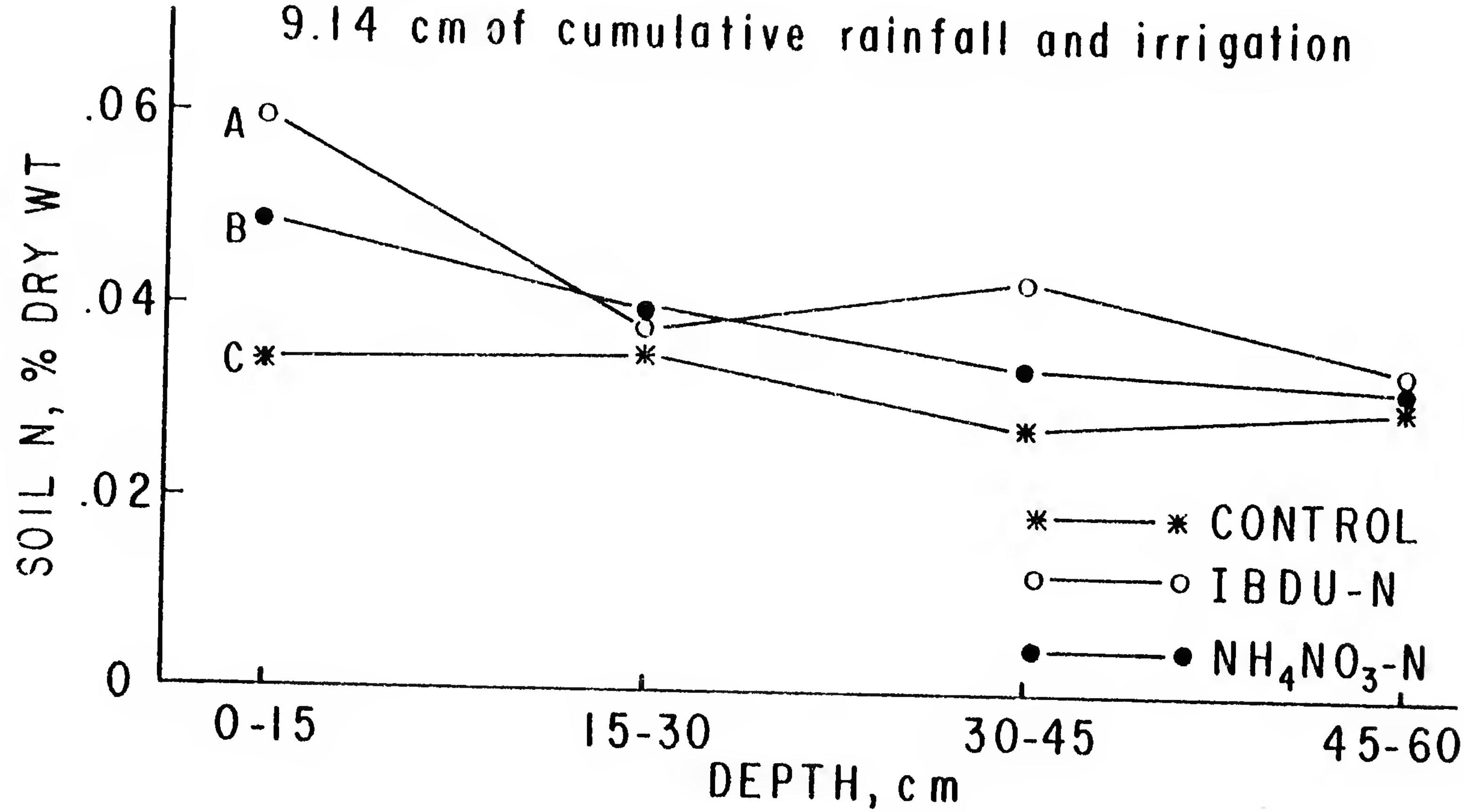


Fig. 7. Effect of N source on total soil N at the 2nd sampling on April 27, 1979. Mean separation by Duncan's multiple range test, 1%. (Expt. 2).

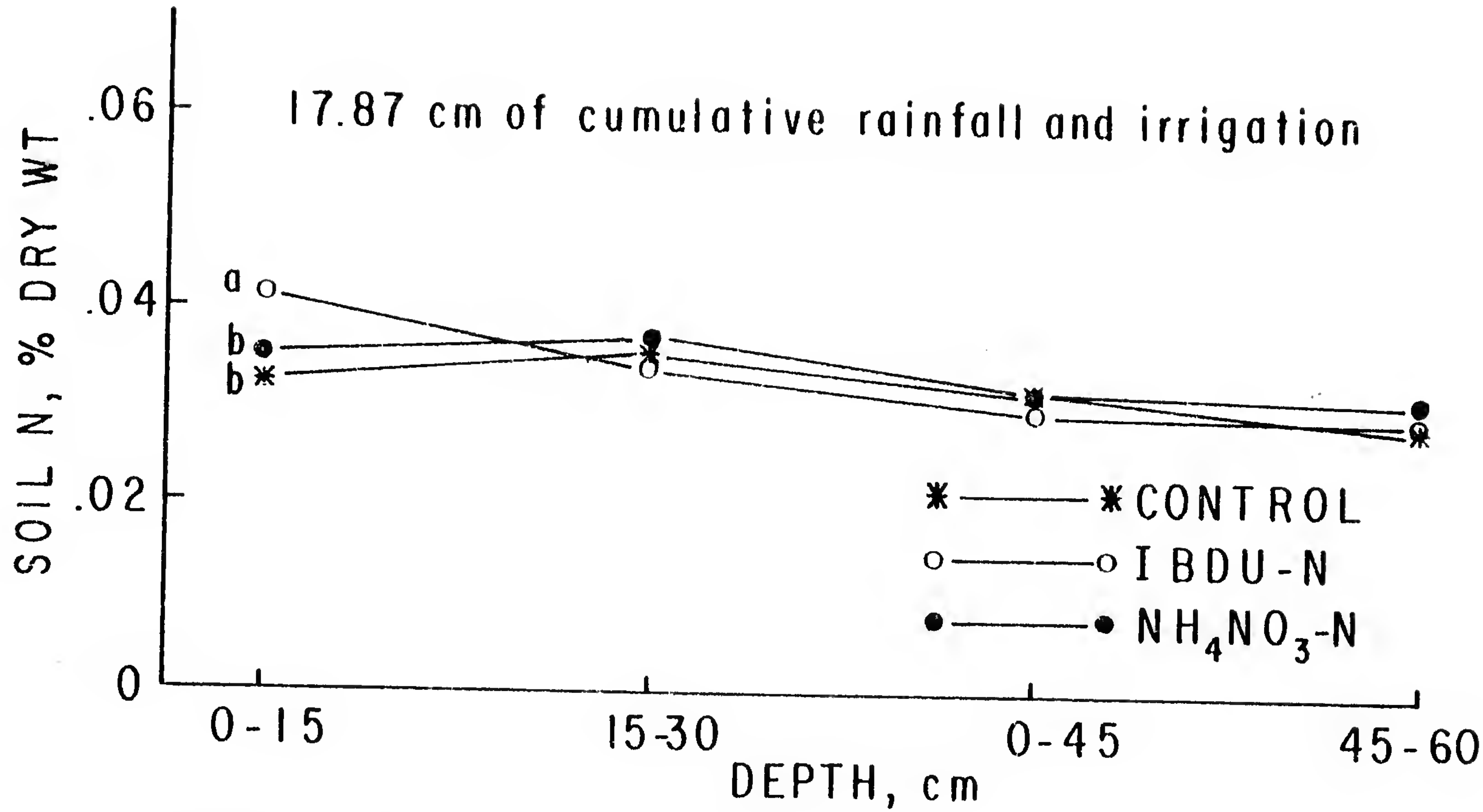


Fig. 8. Effect of N source on total soil N at the 3rd sampling on March 4, 1979. Mean separation by Duncan's multiple range test 5%. (Expt. 2).

Recovery of Fertilizer-N in the Soil-Plant System

The recovery of fertilizer-N in the soil profile and in the tree was calculated by subtracting the N content of the control from the fertilized plots and expressing it as a percent of the amount of N applied. For the NH_4NO_3 treatment in Experiment 1, both soil total N and inorganic N were used in the calculations. Data for the inorganic N procedure indicated that, after 14 weeks, 30% of N apparently remained in the 0- to 60-cm soil profile where NH_4NO_3 had been applied (Table 10). Sixty-six and 41% of N from the IBDU and NH_4NO_3 sources, respectively, remained in this zone when the calculations were based on soil total N values. The discrepancy in the NH_4NO_3-N figures could have resulted from the larger errors inherent in the total N procedure as compared to the inorganic N procedure (12, 13).

In Experiment 2, where the initial soil total N contents were higher as compared to Experiment 1, the total amount of N in the 0- to 60-cm depth was also greater (Table 10). On the basis of total N calculations, 70 and 62% of the applied N were present in the soil from IBDU and NH_4NO_3 sources, respectively. Higher soil N recoveries in this experiment in comparison to those in Experiment 1 probably represented the difference in duration of each experiment, 6 and 14 weeks, respectively.

The relatively high N recoveries from soil where IBDU had been applied in both experiments suggested very little,

Table 10. Nitrogen balance sheet and apparent applied N recovery.[z]

Expt.	N rate	N source	Plant	Soil (0-60cm)		% N recovery				
				Total N	Soluble N	Plant	Soil		Total	
							Total N	Soluble N	Total N	Soluble N
			----------g----------							
1 (14 weeks)	$201.6g/90{,}000cm^2$	Control	1.420	1422.036	8.572	--	--	--	--	--
		IBDU-N	3.015	1555.091	--	0.79	65.99	--	66.78	--
		NH_4NO_3-N	4.295	1505.196	53.014	1.42	41.25	30.57	42.67	31.99
	$6.33g/2828cm^2$	Control	1.420	44.691	0.267	--	--	--	--	--
		IBDU-N	3.015	48.873	--	25.19	65.99	--	91.18	--
		NH_4NO_3-N	4.295	47.305	1.666	45.41	41.25	30.57	86.66	75.98
2 (6 weeks)	$201.6g/90{,}000cm^2$	Control	0.643	2628.330	--	--	--	--	--	--
		IBDU-N	1.601	2769.727	--	0.47	70.17	--	70.64	--
		NH_4NO_3-N	1.689	2753.083	--	0.52	61.92	--	62.44	--
	$6.33g/2828cm^2$	Control	0.643	82.588	--	--		--	--	--
		IBDU-N	1.601	87.031	--	15.13	70.17	--	85.03	--
		NH_4NO_3-N	1.689	86.508	--	16.52	61.92	--	78.74	--

[z]Recovery of N obtained as the difference in total N between unfertilized and fertilized tree plots and expressed as a % of the amount of N applied.

if any, leaching loss of N from this source. Some leaching of N from NH_4NO_3 may have occurred. Other complex processes involved in N reactions, including denitrification and other gaseous losses, may have contributed to lower soil recoveries of N from NH_4NO_3 relative to IBDU.

The recovery of N by the tree was calculated for the total area fertilized (90,000 cm^2); but as the root system occupied a circular area of less than 60 cm diameter (2828 cm^2), N recovery was also calculated for the latter area. In Experiment 1, on the basis of the smaller area, 25 and 45% of the N added were recovered in those trees fertilized with IBDU and NH_4NO_3, respectively. It was only 0.79 and 1.42% for the same respective sources when the larger area was the basis of calculation. The differences in N recoveries from the 2 areas imply a higher efficiency of N use if the fertilizer is applied on a smaller area around the tree rather than on a larger one where the potential for N loss may be great.

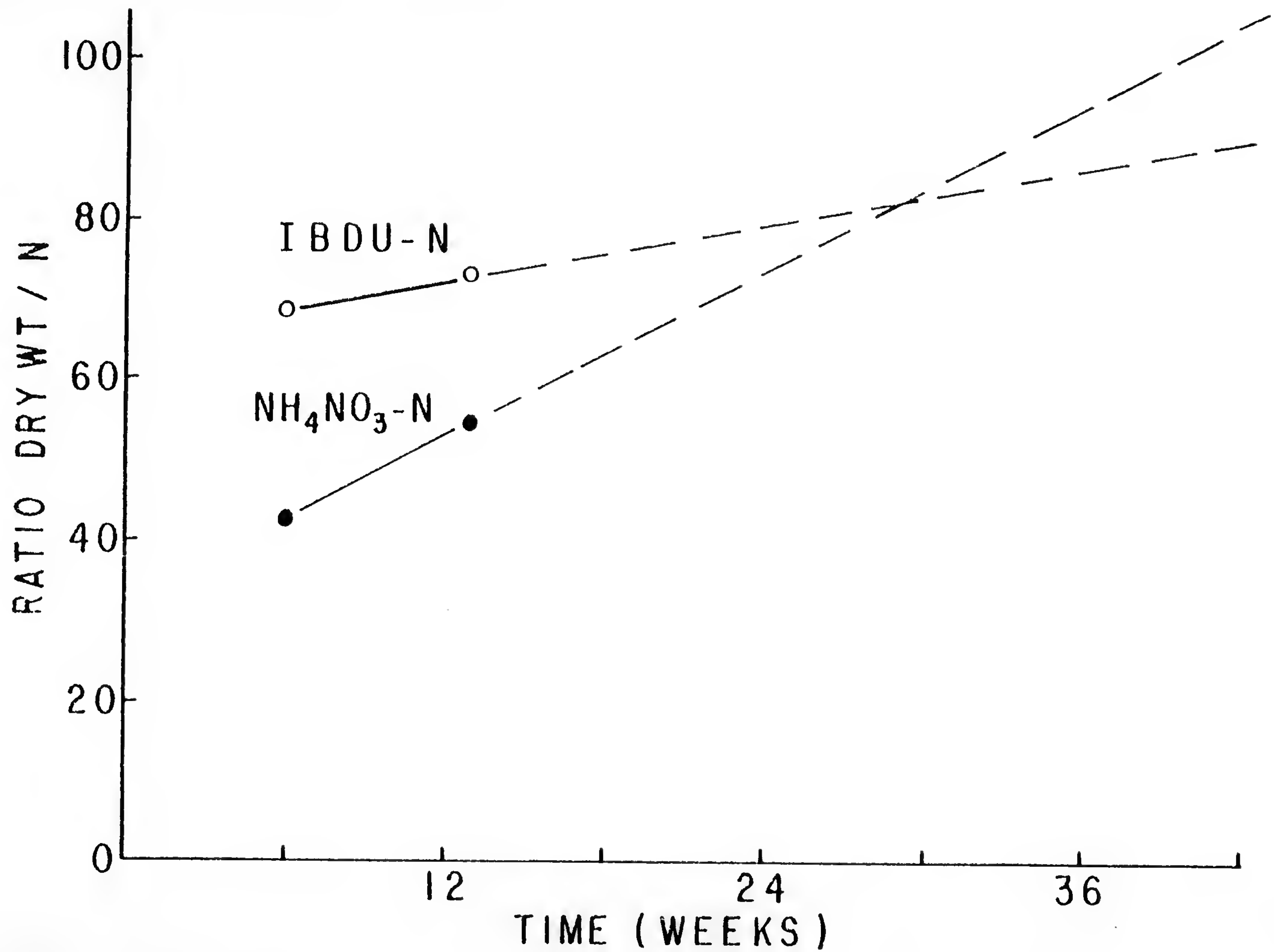
It has been suggested that plant recovery of N by the difference method generally yielded higher values compared to the tracer procedure, presumably because fertilization may stimulate additional N uptake from soil sources (109). This might have contributed to the high N recoveries, particularly where NH_4NO_3 was the source. The higher tree recovery of NH_4NO_3-N appeared to be related to

the ready availability of this fertilizer in comparison to IBDU, a greater proportion of which was retained in the surface soil.

On the basis of the smaller area calculations, trees fertilized with IBDU and NH_4NO_3 in Experiment 2 recovered only 15 and 16%,respectively of the applied N (Table 10). Recoveries from the respective sources were 0.47 and 0.52% for the large area. The lower tree recovery of applied N in Experiment 2 vs. Experiment 1 was partly related to the smaller trees used in the former experiment and partly because the experiment was run only for 6 weeks. The trees did not therefore have enough time to absorb N to the same extent as in Experiment 1. Also, the narrow range in the recovery of applied N seemed to be due to the fact that IBDU-fertilized trees were larger than NH_4NO_3-fertilized trees. If NH_4NO_3-fertilized trees had been of equal size, the difference in the recovery between the 2 fertilizer sources could have been larger.

A common approach for comparing the relationship of fertilizer sources with mineral nutrient absorption by plants in the vegetative growth phase is to relate the total dry matter of the plant to its total nutrient content, i.e., dry weight/total nutrient ratio. The lower this ratio, the greater the nutrient absorption from that source. Assuming the ratio is linear with time, the N status of the trees was projected by plotting the ratio data for

Fig. 9. Projection of relative tree absorption of N from IBDU and NH_4NO_3 sources with time. (Expts. 1 and 2).



RATIO DRY WT / N
100
80
60
40
20
0
12
24
36
TIME (WEEKS)
I B D U - N
NH_4NO_3-N

Experiments 1 and 2 (Fig. 9). Theoretically, up to 26 weeks after fertilizer-N application NH_4NO_3-N would continue to be absorbed more than IBDU-N, but after 28 weeks the reverse would be expected. There is evidence that the period of extended availability from soluble N sources, after the initial flush of growth of vegetable crops, approaches that of the more slowly available N sources (115). In view of the extremely soluble nature of NH_4NO_3, however, most of the N will have probably been depleted from the soil after 26 weeks.

Total apparent N recovery in the soil-plant system in Experiment 1 amounted to 76 and 91 for NH_4NO_3- and IBDU-N, respectively (Table 10). The total N procedure indicated a higher recovery of N from the NH_4NO_3 plots in comparison to the soluble N procedure. The apparently variable total N recovery was probably due to the larger errors associated with the use of the total N procedure in soil analysis vs. the soluble N approach (12, 13).

In Experiment 2, where only soil total N was analyzed, 85 and 78% of the added N from IBDU and NH_4NO_3, respectively, were apparently recovered in the soil-plant system when the small area was the basis of calculation. It was not possible to account for the deficit in N balance in both experiments. Nevertheless, soil N data in Experiment 1 (Fig. 3A-C) and rainfall events of 5.0, 1.3 and 2.6 cm within a 6-day period imply that some leaching of N, at least from

NH_4NO_3, may have contributed to the deficit. Processes involved in the N cycle, including denitrification and other gaseous losses of N may also have been reflected in the unaccounted for part of the balance.

Experiment 3

Nitrogen Distribution in Bearing Orange Trees

Fruit yield and estimate of leaf number

Each of the control, IBDU- and NH_4NO_3-fertilized trees showed fresh fruit yields of 0.7, 3.7 and 3.7 field boxes of 40.8 kg, respectively (Table 11). These data indicated that yields can be severely limited by a lack of N. Nitrogen-fertilized trees had about 4 times as much total fruit dry weight as the control tree. The unreplicated nature of the experiment, however, precluded the establishment of definite conclusions pertaining to the yield data. Nevertheless, it is generally accepted that increased N supply results in increased citrus fruit yield. Data from a Florida experiment (87) with 'Pineapple' orange showed that as the rate of N was increased, up to 202 kg/ha/year, yield increased.

The estimated leaf number of the fertilized trees was in reasonable agreement with the 70,200 leaves estimated by Barnette *et al*. (5) for a grapefruit tree in Florida, but lower than the 92,708 leaves sampled from a 12-year-old 'Valencia' orange tree in California (110). Trees in the

Table 11. Mature tree plot yield and N content parameters, and residual soil N.

Treatment	Boxes fruit/tree[z]	Total fruit dry wt/tree, kg	Fruit N content % dry wt	N removed in fruits g	Estimated total leaf no.	Leaf N content % dry wt	Total leaf N, g	Soil N, (0-120 cm) kg/plot[y]
Unfertilized tree	0.7	8.734	0.58	50.657	52,504	1.84	124.900	17.510
IBDU-fertilized tree	3.7	34.635	0.71	245.908	81,285	2.17	201.100	17.824
NH_4NO_3-fertilized tree	3.7	35.598	0.74	263.425	73,273	2.36	194.600	17.719

[z]Field box of fruit equals 40.8 kg.

[y]Plot area: 6 m diam.

California study were, however, larger as indicated by their height and width. The control tree in the current study had a lower leaf number than either of the fertilized trees by virtue of a lesser leaf density which can be attributed to a lack of N.

Fruit and leaf N content

Several approaches have been used to determine citrus fertilizer needs. One school of thought advocates returning to the soil the amount of nutrients removed in the crop of fruit. Embleton et al. (33) considered this approach unsound, particularly with respect to the less mobile nutrients. Nevertheless, because they represent part of the N balance sheet, data related to crop removal of N when combined with leaf analytical data have a significant potential for guidance in the N management of citrus groves.

The concentration of N in the fruit from the fertilized trees was higher than that of the unfertilized trees (Table 11). As a result, when both total fruit dry weight and N concentration are considered, the amount of N removed in fruit was in the order of NH_4NO_3- > IBDU-fertilized > control trees. Five times more N was removed in fruit from fertilized trees as compared to the control tree. Reitz (89) reported that in Florida 36.3 kg of N are removed in every 20,400 kg of fresh fruit. Recalculation of the data in Table 11 indicates that 32.2 and 29.9 kg of N would be removed in 20,400 kg of fruit from the NH_4NO_3- and IBDU-fertilized trees, respectively.

Leaf N concentration followed the same trend as in the fruit. Nitrogen concentration for the 3 single-tree plots was in the order: NH_4NO_3- > IBDU-fertilized > unfertilized trees. This clearly reflected the more rapid absorption of NH_4NO_3-N over IBDU-N and the control. The total amount of N in the leaves was, however, slightly larger for the IBDU-treated tree because of its greater leaf number. It is doubtful if the greater leaf number is related to IBDU fertilization since the duration of the experiment was short. The total amount of N in the leaves of the fertilized trees was in agreement with the 200 g of N reported by Cameron and Appleman (20) for a 10-year-old 'Valencia' orange tree. This close agreement lends added credence to the procedure used in this study for estimating the leaf number.

Soil Total N Content and Distribution

Fertilized fallow plots received 33% (235.7 g/6 m diameter area) of the total annual amount of fertilizer-N applied to the fertilized tree plots (707.2 g/tree). Three sets of soil samples were collected: on November 9, December 11, 1978, and February 16, 1979. These sampling dates correspond to cumulative rainfall and irrigation of 4.87, 7.50 and 25.90 cm, respectively, since October 25, 1978. Samples were not sufficient for the determination of exchangeable NH_4^+ and NO_3^-; hence, only the total N procedure was used.

At the first sampling, some N from both IBDU and NH_4NO_3 appeared to have moved at least down to the 45-cm depth in

the fallow plots (Fig. 10). The amount of NH_4NO_3-N leached, as reflected by the lower concentration in the 0- to 15-cm depth and higher concentration in the 15- to 45-cm zone, was greater than that of IBDU-N. In the fertilized tree plots, NH_4NO_3-N appeared to be depleted rapidly from the 0- to 15-cm zone, while a considerable amount of IBDU still remained in this zone (Fig. 11). The apparent rapid depletion of NH_4NO_3-N from this zone could be attributed to root absorption in view of the readily available nature of NH_4NO_3 fertilizer. Higher N concentrations, particularly for the IBDU treatment, in the 75- to 105-cm depth, as compared to the control, could have been due to the residual N from previous applications.

Data for the second sampling date (Fig. 12) suggest that some N from both fertilizer sources has leached to the 120-cm depth in the fertilized plots. Soil water contents (Table 12) and evapotranspiration data (Table 8) also tend to support this. Since the movement of N, particularly NO_3-N, in uncropped soils is closely related to water movement in the profile (106), it is likely that some N leached past the 120-cm depth. In the mature tree plots, there was evidence that some N had moved at least to the 75-cm depth when NH_4NO_3 was the fertilizer applied (Fig. 13). It is difficult to trace the movement of N in the soil profile in the presence of a tree, however, because of root absorption.

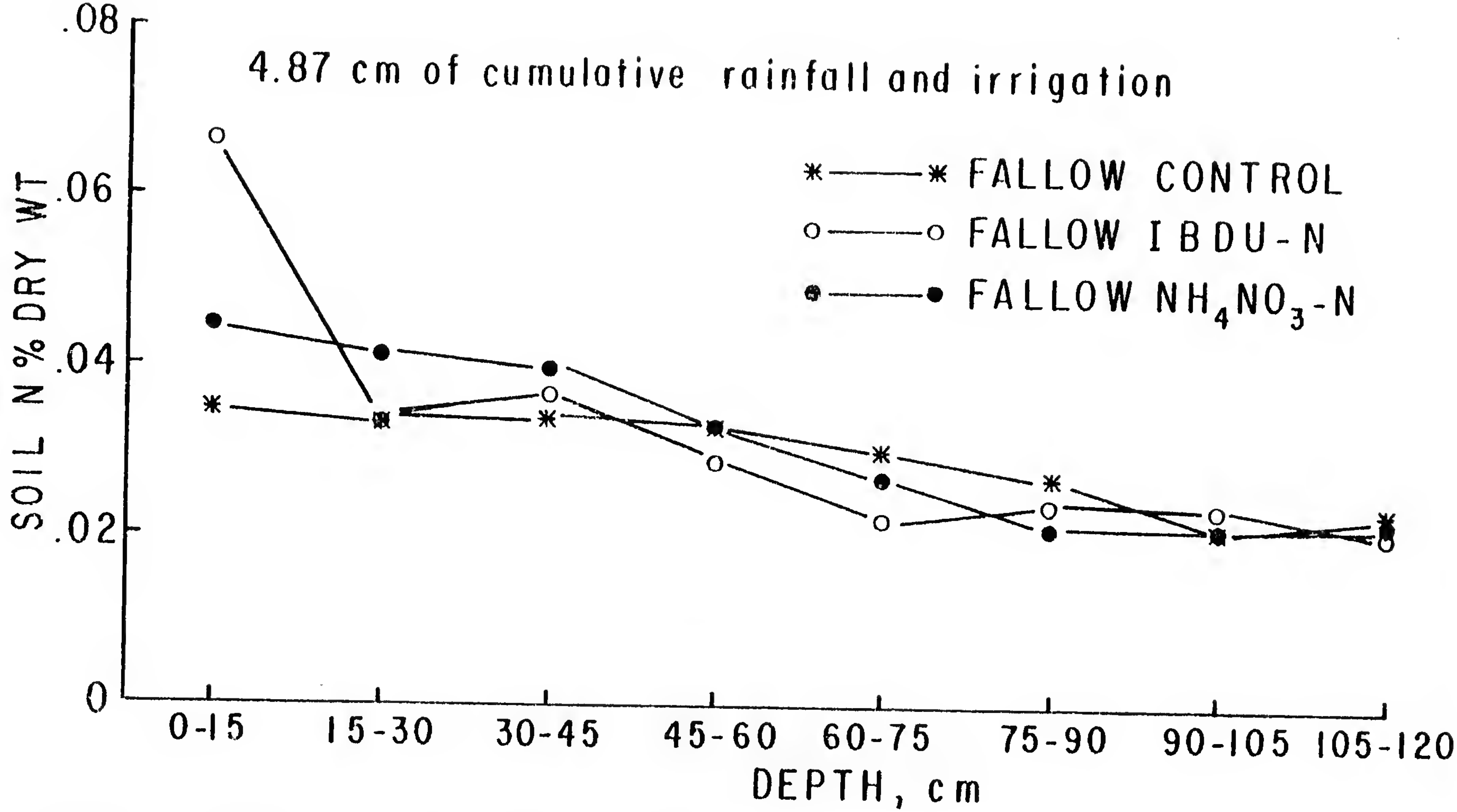


Fig. 10. Effect of N source on total soil N of fallow plots at the 1st sampling on November 9, 1978. (Expt. 3).

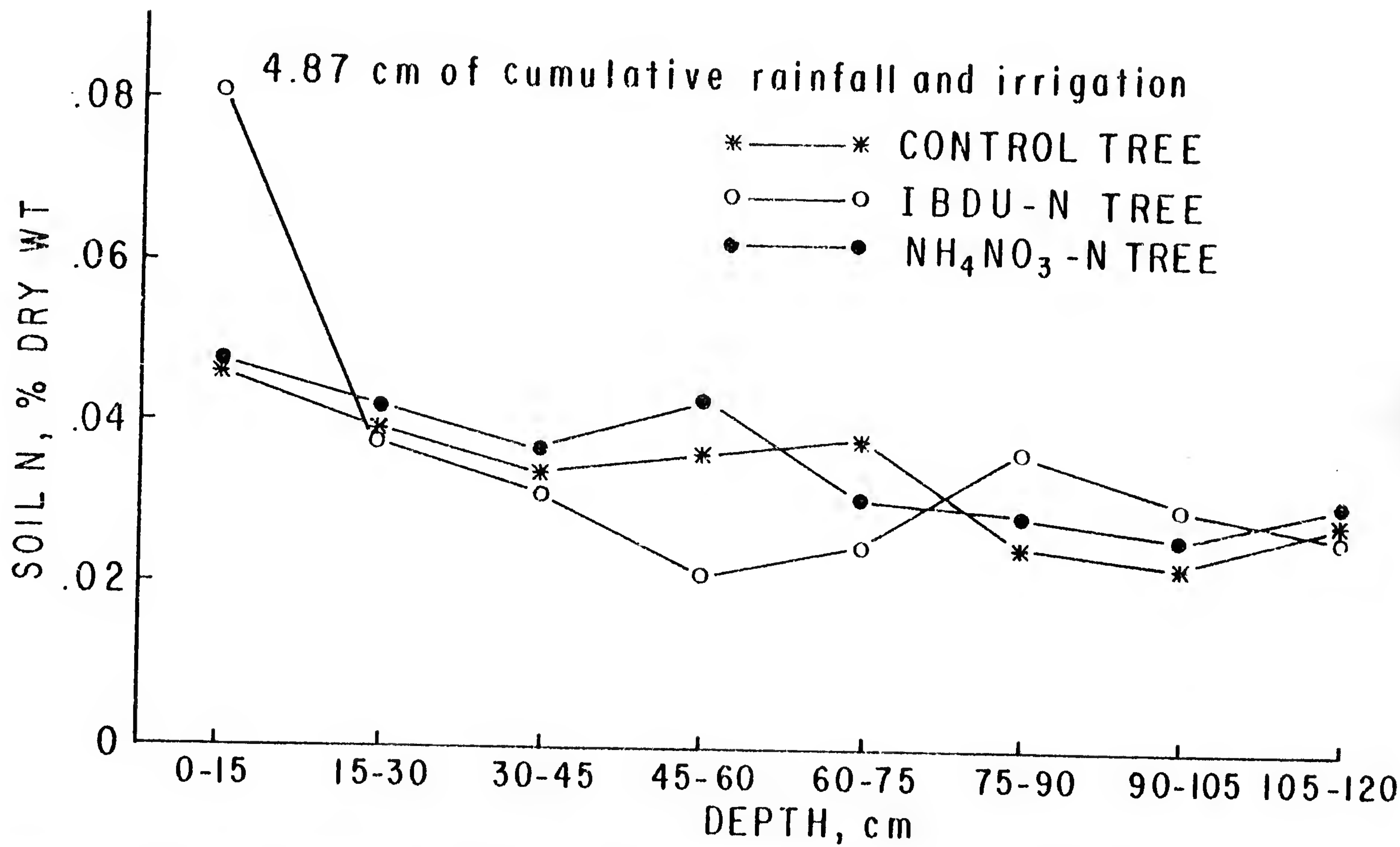


Fig. 11. Effect of N source on total soil N of tree plots at the 1st sampling on November 9, 1978. (Expt. 3).

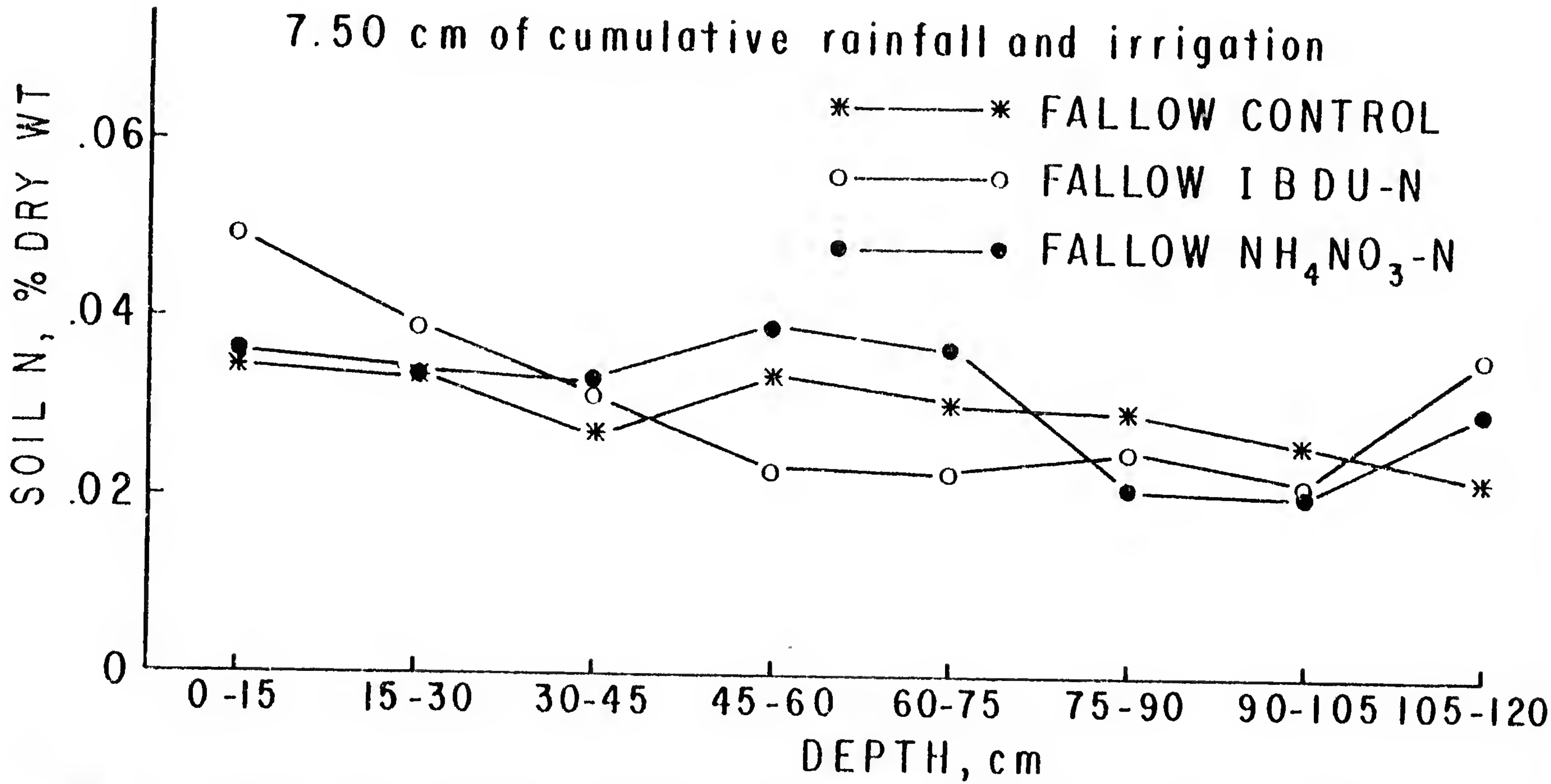


Fig. 12. Effect of N source on total soil N of fallow plots at the 2nd sampling on December 11, 1978. (Expt. 3).

Table 12. Soil water content in the mature tree plots 24 hr. after a rainfall or irrigation event.

Cumulative rainfall and irrigation cm	Depth cm	Soil water content, % by vol.					
		Unfertilized fallow	IBDU fallow	NH_4NO_3 fallow	Unfertilized tree	IBDU tree	NH_4NO_3 tree
4.87	0-15	6.89	6.96	7.74	6.45	5.17	4.14
	15-30	5.88	6.27	6.01	4.66	3.41	3.82
	30-45	6.06	5.94	5.81	5.10	3.76	3.30
	45-60	5.99	5.78	6.00	4.61	4.42	4.30
	60-75	5.86	6.02	5.95	4.13	4.88	2.89
	75-90	5.98	5.92	6.42	3.93	4.44	2.52
	90-105	6.57	6.08	6.38	3.55	4.20	2.48
	105-120	6.26	6.30	6.62	3.51	3.42	4.47
Profile water content, cm		7.41	7.38	7.63	5.38	5.05	4.18
7.50	0-15	5.05	5.72	5.46	3.62	5.32	3.79
	15-30	6.60	9.90	7.42	3.05	5.18	4.70
	30-45	6.67	8.80	6.11	4.06	3.06	3.53
	45-60	6.43	6.91	8.35	3.10	4.76	4.04
	60-75	7.13	8.63	7.15	5.03	6.11	4.45
	75-90	6.60	7.43	7.91	3.97	4.48	4.39
	90-105	7.23	7.73	8.20	3.43	4.24	4.07
	105-120	7.84	7.97	8.15	3.49	5.46	3.66

Table 12 (continued).

Cumulative rainfall and irrigation cm	Depth cm	Soil water content, % by vol.					
		Unfertilized fallow	IBDU fallow	NH_4NO_3 fallow	Unfertilized tree	IBDU tree	NH_4NO_3 tree
	Profile water content, cm	8.02	9.45	8.80	4.45	5.78	4.88
	0-15	5.28	5.16	4.92	5.85	3.94	4.86
	15-30	6.62	7.64	6.65	6.11	4.80	6.55
	30-45	6.41	6.55	6.31	6.05	5.36	5.94
25.90	45-60	6.21	6.75	6.24	6.14	5.54	6.41
	60-75	6.21	6.65	6.84	6.14	6.24	6.58
	75-90	6.14	6.58	6.82	6.70	6.58	6.75
	90-105	6.25	7.21	6.73	6.27	6.51	6.93
	105-120	6.18	6.70	6.85	6.62	6.81	6.65
	Profile water content, cm	7.39	7.98	7.70	7.50	5.86	7.59

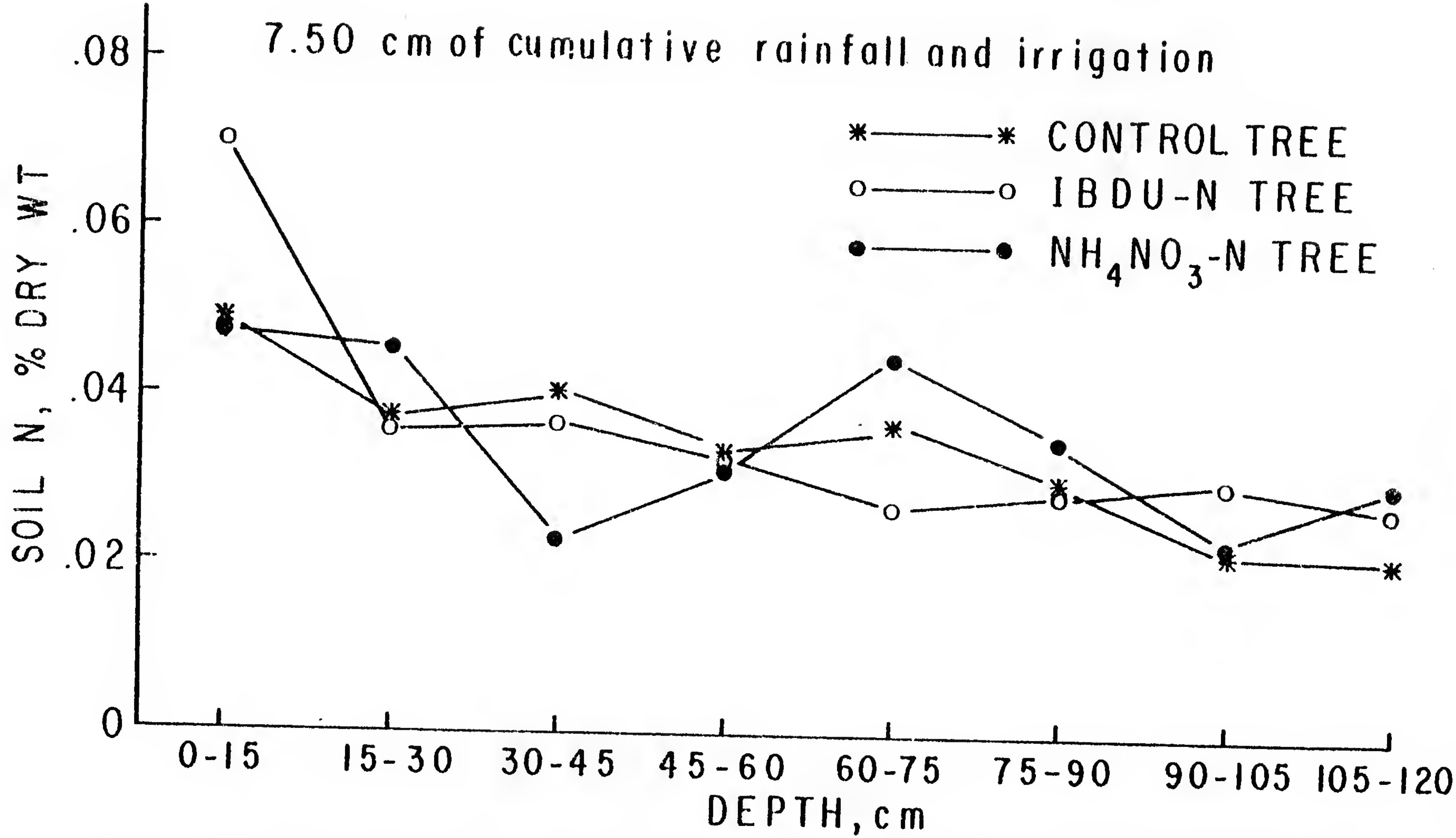


Fig. 13. Effect of N source on total soil N of tree plots at the 2nd sampling on December 11, 1978. (Expt. 3).

As in Experiments 1 and 2, soil total N content generally decreased with time in the tree plots partly because of tree absorption of N. At the last sampling, almost all of the applied NH_4NO_3-N in the fallow and tree plots had dissipated from the 0- to 15-cm depth, but considerable IBDU-N remained (Figs. 14 and 15).

Recovery of Fertilizer-N in the Soil, Fruit and Leaf

The recovery of applied N in the soil, fruit and leaf was calculated by the difference procedure used in both Experiments 1 and 2. Compared to the young tree experiments, however, less confidence can be expected in the N recovery data for Experiment 3. The absence of replications in the mature tree experiment precluded the establishment of plausible conclusions. Furthermore, since the trees had been fertilized for several years it is difficult to separate the effect of previous fertilization on N contents of tree parts and the soil. The use of an empirical procedure in the estimate of leaf total N and the large sampling and analytical errors associated with the soil total N procedure are additional factors which reduce the confidence in the N recovery data.

Nevertheless, the N recovery data (Table 13) may serve a useful purpose in stimulating additional research. The proportion of applied N recovered in the 0- to 120-cm soil depth of the IBDU- and NH_4NO_3-fertilized mature tree plots was 44 and 30%, respectively. The fruits accounted for 27 and 30% of applied N, and the leaves, 11 and 10%

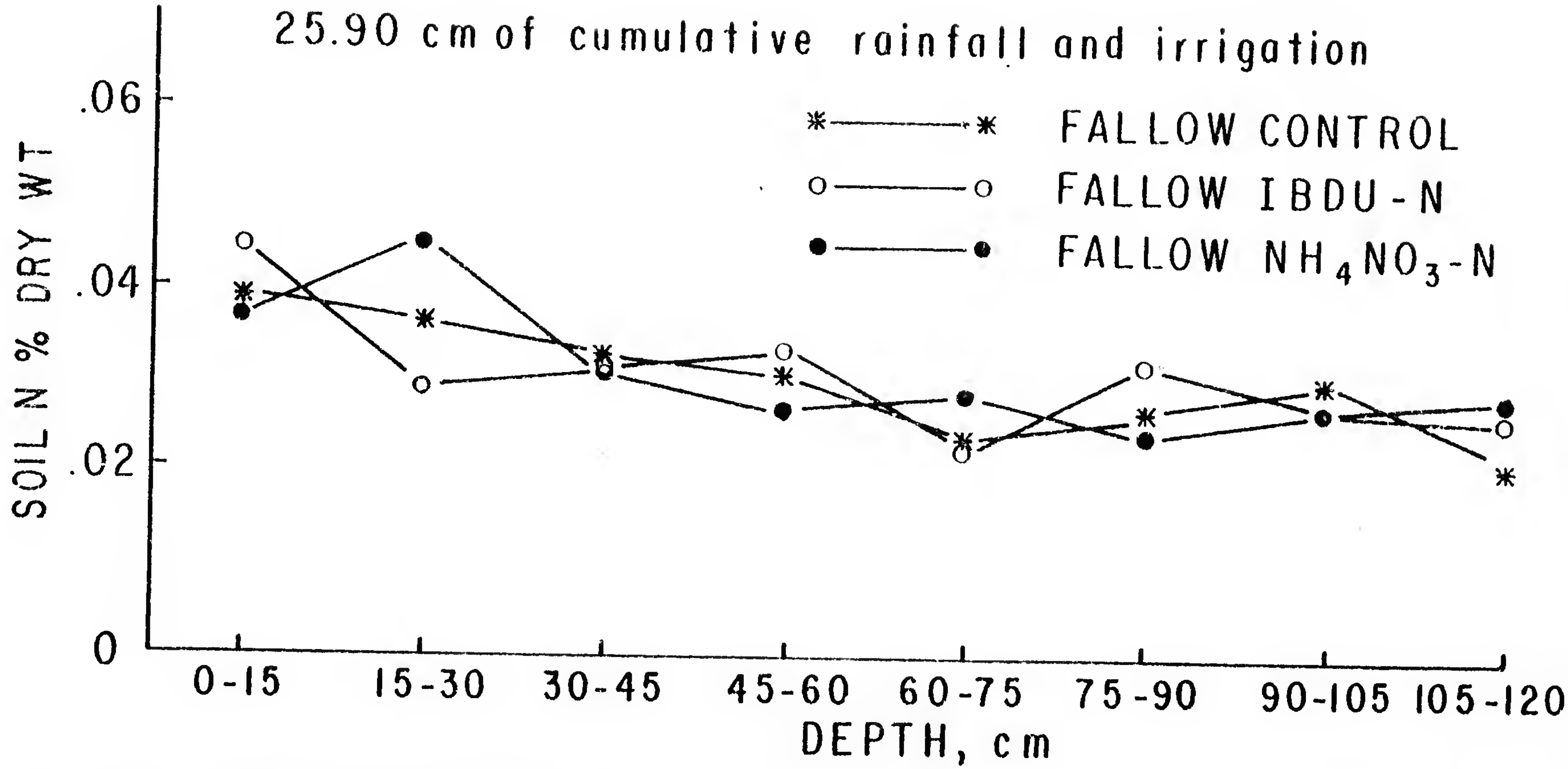


Fig. 14. Effect of N source on total soil N of fallow plots at the 3rd sampling on February 16, 1979. (Expt. 3).

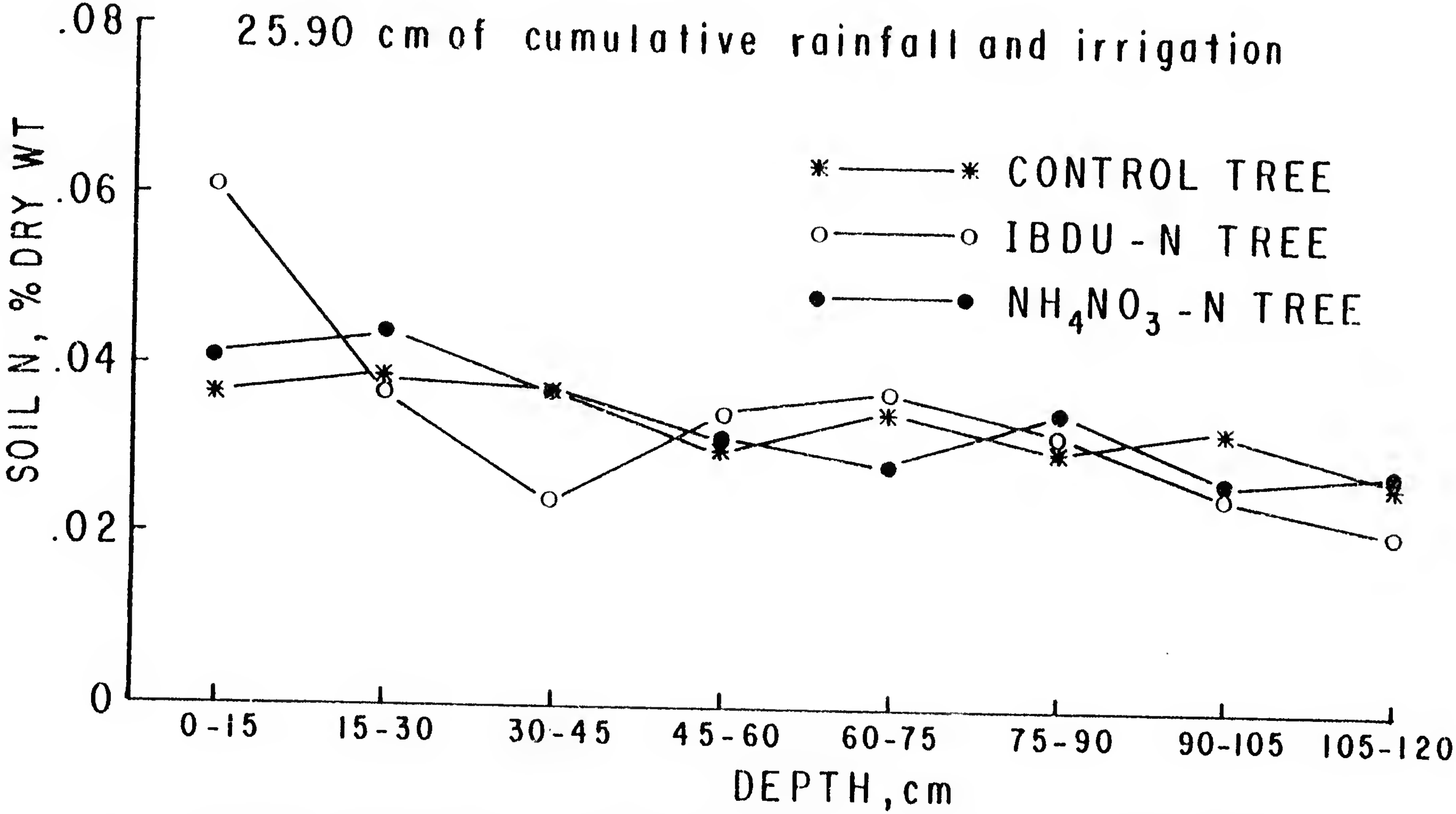


Fig. 15. Effect of N source on total soil N of tree plots at the 3rd sampling on February 16, 1979. (Expt. 3).

Table 13. Apparent applied N recovery (%) in mature tree plots.[z]

Treatment	Fruits	Leaves	Soil	Total
IBDU-fertilized tree	27.60	10.77	44.00	82.77
NH_4NO_3-fertilized tree	30.08	9.85	29.55	69.48

[z]Calculated from the difference in N content, for each N balance component, between the control and fertilized tree plots and expressed as the % of the amount of N applied.

for the same respective sources. The apparent total recovery of applied N when fruits, leaves and the soil are considered amounted to 83% for the IBDU treatment, and 69% for the NH_4NO_3 treatment.

It is suggested that the deficits in the N balance could be partly accounted for in the permanent structures of the tree. Smith (100) estimated that 31% of the total N was found in the leaves of 15-year-old 'Valencia' orange trees in Florida. On this basis, control, IBDU- and NH_4NO_3-treated trees in this experiment would contain 402, 648 and 627 g of N, respectively. It was also indicated that 42% of the total N of the tree was found in parts other than leaves and fruit (100). On the basis of this assumption 13 and 12% of the applied N would be expected to be in tree parts other than fruits and leaves for IBDU- and NH_4NO_3-treated trees, respectively. When these figures are added to the measured recovery of applied N, 95 and 81% of applied N from IBDU and NH_4NO_3 sources, respectively, could be accounted for in the soil-plant system. No account could be made for the remaining 5-19%.

These apparently high recoveries of applied N may indicate that the trees had absorbed some N already present in the soil in addition to that applied in this study. Also, substantial leaching of N may not have been significant. Although the potential for the leaching of N existed (Table 8), the large root systems of the mature trees

may have absorbed a greater portion of the applied N as it moved in the soil profile.

In view of the low nutrient retaining capacity of Florida soils planted to citrus, it has often been suggested that the efficiency of N utilization by citrus is very low (25-30%). In the current study, however, higher recoveries for both young (45%) and bearing (40%) trees are reported when NH_4NO_3 was the N source. These high recoveries imply that citrus trees may be absorbing a greater proportion of fertilizer-N than previously suspected. The unreplicated nature and short duration of the mature tree experiment, however, call for additional adequately replicated experiments. Moreover, it would be beneficial to investigate the N balance of young citrus trees over a period longer than the ones used in this study.

CONCLUSIONS

1. Growth parameters of young citrus trees in short-term experiments, trunk diameter increase, and dry weights of tree component parts and the entire tree, showed no statistical differences due to N sources. There was a trend, however, for N from IBDU and NH_4NO_3 sources to result in greater dry matter, particularly in the more succulent aerial parts, when compared to the control. Leaves from fertilized trees in both fall-winter and spring studies were statistically greater in total dry weight than those from the unfertilized leaves. The apparent lack of statistical differences in growth parameters due to N source was probably related to the short duration of the studies. The trees did not have sufficient time to respond to the treatments.

2. The dry weights of certain tree components as a percent of the total plant were statistically different due to N source, but it is doubtful if they were true differences because the pattern of dry matter distribution paralleled that of the dry matter. These differences were probably the result of selective use of different size trees for each N source.

3. There was a highly significant relationship between N source and N concentration and total N of component tree parts, and total N content of the entire tree. In every case, the order was NH_4NO_3- > IBDU-fertilized > control trees. This confirms that a soluble N source such as NH_4NO_3 is more readily absorbed by the trees in the short-term than a controlled release form of N. Other investigations, however, suggested that the absorption of N from both fertilizer sources might be different in longer periods.

4. Regardless of N source, 30-34% of the total tree N was distributed in fibrous and lateral roots, and 30-33% in the leaves. This illustrates the importance of recovering the entire root system as much as practical in studies of this nature.

5. A greater proportion of the total N in the fertilized tree was distributed in the aerial parts in the spring study than in the fall-winter study, indicating that N absorption and translocation to the aerial parts was greater in spring.

6. Data related to tree growth and N content parameters, and soil total N content did not reveal any statistical differences due to irrigation level in the fall-winter study. The narrow range and short duration of irrigation treatments were probably not sufficient to elicit responses to the treatments.

7. Nitrogen balance data, based on the 2828 cm^2 plot area, showed that total apparent N recovery in the soil-plant system was 91 and 76% for IBDU- and NH_4NO_3-N, respectively. Sixty-six and 30% of applied N from IBDU and NH_4NO_3 sources, respectively, were retained in the 0- to 60-cm soil profile. Twenty-five and 45% from the same respective sources could be accounted for in the young trees. The remaining 9-24% was presumed to have been leached or lost to the atmosphere.

8. In the bearing tree study, no difference was detected in fruit yield between IBDU and NH_4NO_3 sources. Fertilized trees, however, had about 4 times as much yield as the unfertilized tree.

9. The relatively high recovery of applied N in young and bearing trees suggest that substantial leaching of N may not be a major route for N loss from citrus groves established on deep-well drained soils when the fertilizer is applied over the root zone at reasonable rates.

10. A major portion of IBDU-N was retained in the 0- to 15-cm depth, yet the growth response of the IBDU-fertilized young trees was similar to that of NH_4NO_3-fertilized trees. There is, therefore, a potential for a single application of IBDU to nonbearing young citrus trees which are normally fertilized several times a

order to establish if a single application of IBDU is feasible from the standpoint of economy and horticultural considerations.

LITERATURE CITED

1. Adriano, D.C., F.H. Takatori, P.F. Pratt, and O.A. Lorenz. 1972. Soil N balance in selected row-crop sites in Southern California. J. Environ. Qual. 1:278-283.

2. Allison, F.E. 1955. The enigma of soil nitrogen balance sheets. Adv. Agron. 7:214-250.

3. Avnimelech, Y., and J. Raveh. 1976. Nitrate leakage from soils differing in texture and nitrogen load. J. Environ. Qual. 5:79-81.

4. Banwart, W.L., M.A. Tabatabai, and J.M. Bremner. 1972. Determination of ammonium in soil extracts and water samples by an ammonia electrode. Comm. Soil Sci. Plant Anal. 3:449-458.

5. Barnette, R.M., E.F. Debusk, J.B. Hester, and H.W. Jones. 1931. The mineral analysis of a nineteen-year-old 'Marsh' seedless grapefruit. Citrus Indus. 12(3):5-6, 34.

6. Bartholomew, W.V., L.B. Nelson, and C.H. Werkman. 1950. The use of nitrogen isotope N-15 in field studies with oats. Agron. J. 42:100-103.

7. Biggar, J.W. 1978. Spatial variability of N in soils. p. 201-211. In D.R. Neilsen, and J.G. Macdonald (eds.). Nitrogen in the environment. Vol. I. Nitrogen behavior in field soil. Acad. Press, N.Y., San Francisco, Lond.

6 8. Bingham, F.T., S. Davis, and E. Shade. 1971. Water relations, salt balance, and nitrate leaching losses of a 960-acre citrus watershed. Soil Sci. 112:410-418.

9. Bjorkman, E., G. Lundeberg, and H. Nommik. 1967. Distribution and balance of N-15 labelled fertilizer nitrogen applied to young pine trees (Pinus sylvestris L.). Studia Forestalia Seucica, 48:1-23.

10. Bower, C.A., and L.V. Wilcox. 1969. Nitrate content of the Upper Rio Grande as influenced by nitrogen fertilization of adjacent irrigated lands. Proc. Soil Sci. Soc. Amer. 33:971-973.

11. Brams, E.A., and J.G.A. Fiskell. 1967. Variability of root and soil analyses of a 'Valencia' grove sampled in January. Proc. Fla. State Hort. Soc. 80:32-37.

12. Bremner, J.M. 1965. Total nitrogen. p. 1149-1178. In C.A. Black (ed.). Methods of soil analysis. Part 2. Agronomy 9. Amer. Soc. Agron., Madison, Wisc.

13. __________. 1965. Inorganic forms of nitrogen. p. 1179-1237. In C.A. Black (ed.). Methods of soil analysis. Part 2. Agronomy 9. Amer. Soc. Agron., Inc., Madison, Wisc.

14. Cahoon, G.A., and L.H. Stolzy. 1959. Estimating root density in citrus orchards by the neutron moderation method. Proc. Amer. Soc. Hort. Sci. 74: 322-327.

15. __________. 1960. Citrus root density in relation to water use. Calif. Citrog. 45:318, 323.

16. Calvert, D.V. 1975. Nitrate, phosphate, and potassium movement into drainage lines under 3 soil management practices. J. Environ. Qual. 4: 183-186.

17. __________, and H.J. Reitz. 1964. Effects of rate and frequency of fertilizer applications on yield and quality of 'Valencia' oranges in the Indian River area. Proc. Fla. State Hort. Soc. 77:36-41.

18. __________, and H.T. Phung. 1971. Nitrate-nitrogen movement into drainage lines under different soil management systems. Proc. Soil and Crop Sci. Soc. Fla. 31:229-232.

19. Cameron, S.H., and O.C. Compton. 1945. Nitrogen in bearing orange trees. Proc. Amer. Soc. Hort. Sci. 46:60-68.

20. __________, and D. Appleman. 1933. The distribution of total nitrogen in the orange tree. Proc. Amer. Soc. Hort. Sci. 30:341-348.

21. Carlton, A.B., and A.A.R. Hafez. 1973. N-14 nitrogen fertilizer tracing experiments in San Joaquin Valley. Calif. Agr. 27(11):10-13.

22. Chapman, H.D. 1968. Mineral nutrition of citrus. p. 127-289. In W. Reuther, L.D. Batchelor, and H.J. Webber (eds.). Citrus industry, Rev. ed. II. Univ. Calif., Div. Agr. Sci., Berkeley, Calif.

23. Colman, E.A. 1946. A laboratory study of lysimeter drainage under controlled soil moisture tension. Soil Sci. 62:365-382.

24. Cooper, D.R., D.G. Hill-Cottingham, and C.P. Lloyd-Jones. 1976. Distribution and identity of labelled products following autumn application of N-15-labelled urea or potassium nitrate fertilizers to apple trees. J. Sci. Food Agr. 27:266-272.

25. Cooper, W.C., A Peynado, J.R. Furr., R.H. Hilgeman, G.A. Cahoon, and S.B. Boswell. 1963. Tree growth and fruit quality of 'Valencia' oranges in relation to climate. Proc. Amer. Soc. Hort. 82:180-192.

26. DeVitt, D., J. Letey, L.J. Lund, and J.W. Blair. 1976. Nitrate-nitrogen movement through soil as affected by soil profile characteristics. J. Environ. Qual. 5:283-288.

27. Duke, H.R., and H.R. Haise. 1973. Vacuum extractors to assess deep percolation losses and chemical constituents of water. Proc. Soil Sci. Soc. Amer. 37:963-964.

28. Edwards, P.P., and R.D. Hauck. 1974. Nitrogen-15-depleted versus nitrogen-15-enriched ammonium sulfate as tracers in nitrogen uptake studies. Proc. Soil Sci. Soc. Amer. 38:765-767.

29. Embleton, T.W., and W.W. Jones. 1978. Nitrogen fertilizer management programs, nitrate-pollution potential, and orange productivity. p. 275-295. In D.R. Nielsen and J.G. MacDonald (eds.). Nitrogen in the environment. Vol. I. Nitrogen behavior in field soil. Acad. Press., N.Y., San Francisco, Lond.

30. __________. 1974. Foliar-applied nitrogen for citrus. J. Environ. Qual. 3:338-391.

31. __________, and R.L. Branson. 1974. Leaf analysis proves useful in increasing efficiency of nitrogen fertilization of oranges and reducing nitrate pollution potential. Comm. Soil Sci. Plant Anal. 5(5):437-442.

32. __________, C.K. Labanauskas, and W. Reuther. 1973. Leaf analysis as a diagnostic tool and guide to fertilization. p. 183-210, 447-495. In W. Reuther (ed.). Citrus industry, Rev. ed. III. Univ. Calif. Div. Agr. Sci., Berkeley, Calif.

33. __________, H.J. Reitz, and W.W. Jones. 1973. Citrus fertilization. p. 122-182. In W. Reuther (ed.). Citrus industry, Rev. ed. III. Univ. Calif. Div. Agr. Sci., Berkeley, Calif.

34. Erickson, A.E., and B.G. Ellis. 1971. The nutrient content of drainage water from agricultural land. Mich. State Univ. Agr. Expt. Sta., East Lansing, Res. Bull. 31.

35. Forbes, R.B., C.C. Hortenstine, and F.W. Bistline. 1974. Nitrogen, Potassium and soluble salts in the soil solution in a Blanton fine sand. Soil and Crop Sci. Soc. Fla. 33:202-204.

36. Gallagher, P.E., and W.V. Bartholomew. 1964. Comparison of nitrate production and other procedures in determining nitrogen availability in southeastern Coastal Plain soils. Agron. J. 56:179-184.

37. Graetz, D.A., L.C. Hammond, and J.M. Davidson. 1974. Nitrate movement in a Eustis fine sand planted to millet. Proc. Soil and Crop Sci. Soc. Fla. 33: 157-160.

38. Grasmanis, V.O., and D.J.D. Nicholas. 1971. Annual uptake of N-15-labelled ammonia and nitrate in young 'Jonathan' MM104 apple trees grown in solution culture. Plant and Soil. 35:95-112.

39. Hagillih, D.A. 1976. The effect of citrus rootstocks and irrigation level on the efficiency of mineral nutrient absorption. MS Thesis, Univ. of Fla., Gainesville.

40. Hajdukovic, M., M. Jakovljevic, and V. Vagand. 1967. Comparison of 3 methods of measuring soil moisture. p. 117-124. In A. Guillon (ed.). Isotope and radiation techniques in soil physics and irrigation studies. Proc. Symp. Intern. Atomic Energy Agency, Vienna.

41. Hamamoto, A.D. 1966. Isobutylidene diurea as a slow acting nitrogen fertilizer and the studies in this field in Japan. Proc. no. 90. The Fertilizer Soc., Lond.

42. Harding, R.B., T.W. Embleton, and W.W. Jones. 1963. Leaching and gaseous loss of N from some non-tilled California soils. Calif. Citrog. 48: 317-324.

43. Harmsen, G.W., and G.J. Kokenbrander. 1965. Soil inorganic nitrogen. p. 43-92. In W.V. Bartholomew, and F.E. Clark (eds.). Soil nitrogen. Agronomy 10. Amer. Soc., Agron., Madison, Wisc.

44. Hauck, R.D. 1967. The use of N-15 in forest soil-fertilizer nitrogen investigations. p. 64-71. In G.W. Gengston, R.H. Brendemuehl, W.L. Pritchett, and W.H. Smith (eds.). Forest fertilization -- Theory and practice. Tenn. Valley Auth., Muscle Shoals, Al.

45. Hill-Cottingham, D.G., and C.P. Lloyd-Jones. 1975. Nitrogen-15 in apple nutrition investigations. J. Sci. Food Agr. 26:165-173.

46. Holt, R.F., G.R. Blake, W.B. Woorhees, D.H. Boelter, and A.S. Robertson. 1961. Soil moisture survey of some representative Minnesota soils. U.S.D.A. ARS, 41-48.

47. Huckle, H.F., F. Sodek, III, and V.W. Carlisle. 1978. Soil temperature classes, coatings, taxadjuncts and series correlations. p. 33-43. In V.W. Carlisle and F.L. Moritz (eds.). Florida soil identification handbook. Univ. Fla. Coop. Ext. Serv., Gainesville.

48. Hughes, T.D. 1976. Nitrogen release from isobutylidene diurea: Soil pH and fertilizer particle size. Agron. J. 68:103-106.

49. Ito, O., and K. Kumazawa. 1976. N assimilation in sunflower leaves and upward and downward transport of N. Soil Sci. Plant. Nutr. 22(2):181-189.

50. Jansson, S.L. 1963. Balance sheet and residual effects of fertilizer nitrogen in a 6-year-old study with N-15. Soil Sci. 95:31-37.

51. Jones, W.W., and P.F. Pratt. 1972. Nitrates below root zone in Upper Santa Ana Basin orchards. Citrog. 57(12):464-466.

52. Koo, R.C.J. 1953. A study of soil moisture in relation to absorption and transpiration by citrus. Ph.D. Diss., Univ. Fla., Gainesville.

53. __________. 1961. The distribution and uptake of soil moisture in citrus groves. Proc. Fla. State Hort. Soc. 74:86-90.

54. __________. 1978. Critique . . . Nitrogen fertilizer management programs, nitrate-pollution potential, and orange productivity. p. 303-307. In D.R. Nielsen and J.G. MacDonald (eds.). Nitrogen in the environment. Vol. I. Nitrogen behavior in field soil. Acad. Press, N.Y., San Francisco, Lond.

55. __________. 1969. Evapotranspiration and soil moisture determination as guides to citrus irrigation. Proc. First Citrus Symp. III:1725-1730.

56. __________, and L.C. Hammond. 1964. A comparison of gravimetric, tensiometric and neutron scattering methods of measuring water in Lakeland fine sand. Proc. Soil and Crop Sci. Soc. Fla. 24:63-68.

57. Kubota, S., T. Kato, S. Akao, and C. Bunya. 1976. N-15 absorption and translocation by Satsuma mandarin trees. III. Behavior of N supplied in early spring. Chem. Abstr. 95(5):31961y.

58. __________, A. Tadashi, S. Akao, and C. Bunya. 1976. N-15 absorption and translocation by Satsuma mandarin trees. IV. Behavior of N supplied in early summer. Chem. Abstr. 85(5):3192z.

59. Labanauskas, C.K., and M.F. Handy. 1972. Amounts of nutrients removed by 'Valencia' orange in a California grove. HortScience. 7:510-511.

60. Letey, J., J.W. Blair, D. Devitt, L.J. Lund, and P. Nash. 1971. Nitrate-nitrogen in effluent from agricultural tile drains in California. Hilgardia. 45(9):289-319.

61. Lund, L.J., D.C. Adriano, and P.F. Pratt. 1974. Nitrate concentration in deep cores as related to profile characteristics. J. Environ. Qual. 3:78-82.

62. Lunt, O.R. 1971. Controlled-release fertilizers: Achievements and potential. J. Agr. Food Chem. 19:797-800.

63. Marchal, J., and J.J. Lacoeuille. 1969. Bilan mineral du mandarinier 'Wilking'. Influence de l'etat vegetatif de l'arbre sur sa composition minerale. Fruit d'Outre-Mer. 24:299-318.

64. Marsh, A.W. 1973. Irrigation. p. 230-279. In W. Reuther (ed.). Citrus Industry, Rev. ed. III. Univ. Calif. Div. Agr. Sci.

65. McGarity, J.W., and J.A. Rajaratnam. 1973. Apparatus for the measurement of losses of N as gas from the field and simulated field environments. Soil Biol. Biochem. 5:121-131.

66. Mead, D.J. 1971. Movement of added N and P in a pine forest ecosystem. Ph.D. Diss., Univ. of Fla., Gainesville.

67. Milham, P.J., A.S. Awad, R.E. Paull, and J.H. Bull. 1970. Analysis of plants, soils and waters for nitrate by using an ion-selective electrode. Analyst. 95:751-757.

68. Miller, R.J., and D.W. Wolfe. 1978. Nitrogen inputs and outputs: A valley basin study. p. 163-172. In D.R. Nielsen and J.G. MacDonald (eds.). Nitrogen in the environment. Vol. I. Nitrogen behavior in field soil. Acad. Press, N.Y., San Francisco, Lond.

69. __________, and R.B. Smith. 1976. Nitrogen balance in the San Joaquin Valley. J. Environ. Qual. 5:274-278.

70. Miller, S.S. 1979. Effect of nitrogen fertilization and cultural systems on growth and N levels in 'Delicious' apple trees. HortScience. 14(3): 540 (Abstr.).

71. Miner, G.S., J.P. Lilly, and D.L. Terry. 1978. Nitrogen release characteristics of isobutylidene diurea and its effectiveness as a source of N for flue-cured tobacco. Agron. J. 70:434-438.

72. Moberg, E.L., D.V. Waddington, and J.M. Duich. 1970. Evaluation of slow-release N sources on 'Merion' Kentucky blue grass. Proc. Soil Sci. Soc. Amer. 34:335-339.

73. Muhammad, S., and K. Kumazawa. 1972. Use of optical spectrographic N-15 analyses to trace N applied at the heading stage of rice. Soil Sci. Plant Nutr. 18(4):143-146.

74. Nelson, L.B., and R.D. Hauck. 1965. Nitrogen fertilizers: Progress and Problems. Agr. Sci. Rev. 3:38-47.

75. Overrein, L.N. 1969. Lysimeter studies on tracer N in forest soil: 2. Comparative losses of N through leaching and volatization after the addition of urea-, ammonium-, and nitrate-N-15. Soil Sci. 107:149-159.

76. Parr, J.F. 1967. Biochemical considerations for increasing the efficiency of fertilizer nitrogen. Soil and Fert. 30:207-213.

77. __________. 1973. Biochemical considerations for maximizing the efficiency of fertilizer nitrogen. J. Environ. Qual. 2:75-84.

78. Patten, K.D., and P.A. Domoto. 1979. Effect of trickle irrigation and nitrogen injection on apple trees. HortScience, 14(3):538 (Abstr.).

79. Petersen, R.G., and L.D. Calvin. 1965. Sampling. p. 54-72. In C.A. Black (ed.). Methods of soil analysis. Part I. Agronomy 9. Amer Soc. Agron., Madison, Wisc.

80. Power, J.F. 1968. What happens to fertilizer nitrogen in the soil? J. Soil and Water Conservn. 23(1):10-12.

81. Pratt, P.D., W.W. Jones, and V.E. Hursaker. 1972. Nitrate in deep soil profiles in relation to fertilizer rates and leaching volume. J. Environ. Qual. 1:97-102.

82. __________, L.J. Lund, and J.M. Rible. 1978. An approach to measuring leaching of nitrate from freely drained irrigated fields. p. 223-265. In D.R. Nielsen and J.G. MacDonald (eds.). Nitrogen in the environment. Vol. I. Nitrogen behavior in field soil. Acad. Press, N.Y., San Francisco, Lond.

83. __________, S. David, and R.G. Sharpless. 1976. A 4-year field trial with animal manures. I. Nitrogen balances and yields. Hilgardia. 44(5): 99-112.

84. Pritchett, W.L., C.F. Eno, and M.N. Malik. 1959. The nitrogen status of the mineral soils of Florida. Proc. Soil Sci. Soc. Amer. 23:127-130.

85. Rajendra, P., G.B. Rajale, and B.A. Lakhide. 1971. Nitrification retarders and slow-release nitrogen fertilizers. Adv. Agron. 23:337-3-3.

86. Raper, C.D., Jr., D.L. Osmond, M. Wann, and W.W. Weeks. 1978. Interdependence of root and shoot activities in determining nitrogen uptake of roots. Bot. Gaz. 139(3):289-294.

87. Reese, R.L., and R.C.J. Koo. 1975. N and K effects on leaf analysis, tree size, and yield of three major Florida orange cultivars. J. Amer. Soc. Hort. Sci. 100:195-198.

88. Reitz, H.J. 1956. Timing fertilization of citrus in the Indian River area. Proc. Fla. State Hort. Soc. 69:58-64.

89. __________. 1961. Citrus needs adequate nutrition. Better crops with plant food 45(4):10-14, 31.

90. __________, C.D. Leonard, I. Stewart, R.C.J. Koo, C.A. Anderson, R.L. Reese, D.V. Calvert, and P.F. Smith. 1972. Recommended fertilizer and nutritional sprays for citrus. Univ. Fla. Agr. Exp. Bul. 536C.

91. Rennie, P.J. 1966. A forest sampling procedure for nutrient uptake studies. Commonwealth Forest Rev. 45:119-128.

92. Richards, J.E. 1954. Performance of tensiometers under citrus trees on Lakeland fine sand. MS Thesis, Univ. Fla., Gainesville.

93. Richards, L.A., and M.R. Huberty. 1941. Moisture studies under citrus using tensiometers. Proc. Amer. Soc. Hort. Sci. 30:73-79.

94. __________, and C.H. Wadleigh. 1952. Soil water and plant growth. p. 73-251. In B.T. Shaw (ed.). Soil physical conditions and plant growth. Agronomy Mono. II. Acad. Press Inc., New York, N.Y.

95. Richards, S.J., and A.W. Marsh. 1961. Irrigation based on soil suction measurements. Proc. Soil Sci. Soc. Amer. 25:65-69.

96. Reikerk, H., and S.P. Gessel. 1965. Mineral cycling in a Douglas fir forest stand. Health Phys. 11:1363-1369.

97. Roston, E.D. 1977. Measuring N loss for denitrification. Calif. Agr. 31(1):12-13.

98. Rothpart, H.A. 1964. Mechanical design and system handbook. McGraw-Hill Book Co., New York.

99. Smith, P.F. 1966. Leaf analysis of citrus. p. 208-228. In N.F. Childers (ed.). Temperate to tropical fruit nutrition. 2nd ed. Horticultural Publications, Rutgers Univ., New Brunswick, New Jersey.

100. __________. 1963. Nitrogen--in citrus fertilization. Citrus Indus. 44(1):9-10.

101. __________. 1967. Nutritional responses of citrus grown in a humid climate. Proc. XVII Intern. Congr. 3:197-214.

102. Spencer, W.F.A., MacKenzie, and F.G. Viets, Jr. 1966. The relationship between soil tests for available nitrogen and nitrogen uptake by various irrigated crops in the western states. Proc. Soil Sci. Soc. Amer. 30:480-485.

103. Starr, J.L., F.E. Broadbent, and P.R. Stout. 1974. A comparison of N-15-depleted and N-15-enriched fertilizers as tracers. Proc. Soil Sci. Soc. Amer. 38:266-267.

104. Stolzy, L.H., and G.A. Cahoon. 1957. A field-calibrated portable neutron rate meter for measuring soil moisture in citrus orchards. Proc. Soil Sci. Soc. Amer. 21:571-575.

105. __________, and T.E. Szuskiew. 1957. Measurement of soil moisture. Calif. Agr. 11(4):21-22, 37.

106. Terman, G.L., and S.E. Allen. 1970. Leaching of soluble and slow-release N and K fertilizers from Lakeland sand under grass and fallow. Proc. Soil and Crop Sci. Soc. Fla. 30:130-140.

107. Terry, D.L., and C.B. McCants. 1970. Quantitative prediction of leaching in field soils. Proc. Soil Sci. Soc. Amer. 34:271-276.

108. Thomas, G.W., and B.J. Barfield. 1974. The unreliability of tile effluent for monitoring subsurface nitrate-nitrogen losses from soils. J. Environ. Qual. 3:183-185.

109. Tucker, T.C., and R.D. Hauck. 1978. Removal of N by various irrigated crops. p. 135-167. In P.F. Pratt (ed.). Proceedings of the national conference on the management of nitrogen in irrigated agriculture. Univ. Calif., Div. Agr. Sci., Davis, Calif.

110. Turrel, F.M. 1961. Growth of photosynthetic area of citrus, Bot. Gaz. 122:285-298.

111. __________, M.J. Garber, W.W. Jones, W.C. Cooper, and R.H. Young. 1969. Growth equations and curves for citrus trees. Hilgardia. 39(16):429-445.

112. Tyler, K.B., and F.E. Broadbent. 1958. N uptake by ryegrass from 3 tagged ammonium fertilizers. Proc. Soil Sci. Soc. Amer. 22:231-234.

113. Van Schreven, D.A. 1970. Leaching of nitrogen and potassium in polders reclaimed from Lake Ijssel. Plant and Soil. 33:629-643.

114. Volk, G.M. 1975. Fertilizers and fertilization. Univ. Fla. Exten. Serv., Bul 183-B.

115. __________, 1954. The value of organic nitrogen in vegetable fertilizers. Proc. Fla. State Hort. Soc. 67:153-157.

116. __________, and G.C. Horn. 1975. Response curves of various turfgrasses to application of several controlled-release nitrogen sources. Agron. J. 67:201-204.

117. __________, and A.E. Duderk. 1976. Abnormal color response of turf ryegrass to top-dressed isobutylidene diurea. Agron. J. 68:534-536.

118. Walker, L.C. 1958. Isotope trace methods in tree nutrition. 1st North American Forest Soils Confr. Agr. Exp. Sta. Mich. State Univ., East Lansing.

119. Wallace, A. 1953. N absorption and translocation by citrus cuttings at different root temperatures. Proc. Amer. Soc. Hort. Sci. 61:89-94.

120. __________. 1954. Ammonium and nitrate N absorption by citrus. Soil Sci. 78:89-94.

121. __________, W.H. Cameron, and R.T. Mueller. 1951. Seasonal use and loss of nutrients and dry matter in orange trees. Proc. Amer. Soc. Hort. Sci. 58:5-10.

122. __________, Z.I. Zidan, R.T. Mueller, and C.P. North. 1954. Translocation of N in citrus trees. Proc. Amer. Soc. Hort. Sci. 64:87-104.

123. Wander, I.W. 1951. Soil correlations--Composition of water draining from grove areas. Univ. Fla. Agr. Exp. Sta. Ann. Rept.

124. Weinbaum, S.A., M.L. Merwin, and T.T. Muraoka. 1978. Seasonal variation in nitrate uptake efficiency and distribution of absorbed nitrogen in non-bearing prune trees. J. Amer. Soc. Hort. Sci. 103:516-519.

125. Weir, C.C. 1969. Investigations on the mineral nutrition of citrus in the Caribbean area. Univ. West Ind., St. Augustine. Tech. Bul. 2.

126. White, E.H., and W.L. Prichett. 1970. Water table control and fertilization for pine production in the flatwoods. Univ. Fla. Agr. Exp. Sta. Bul. 743.

127. Yonemaya, T., and K. Kumazawa. 1974. A kinetic study of assimilation of N-15-labelled ammonium in rice seedling roots. Plants and Cell Physiol. 15: 655-661.

128. __________, K. Komamura, and K. Jumazawa. 1975. N transport in intact corn roots. Soil Sci. Plant Nutr. 21(4):371-377.

129. Yuda, E. 1977. Nutritional problems in citrus culture in Japan. Proc. Int. Soc. Citriculture. 1:5-9.

130. Zamyatina, V.B., N.I. Borisova, N.M. Varyushkina, S.V. Burtzeva, and L.I. Kirpaneva. 1968. Investigations on the balance and use of N-15-tagged fertilizer nitrogen by plants in soils. 9th Intern. Congr. Soil Sci. Trans. II:513-521.

131. Zidan, Z.I., and A. Wallace. 1954. Concentrations of 5 macronutrient elements in orange fruits collected at different stages of maturity. Proc. Amer. Soc. Hort. Sci. 63:53-58.

BIOGRAPHICAL SKETCH

Daniel Apollo Hagillih was born January 1, 1946, at Maridi, Sudan, where he attended his elementary school. He pursued his intermediate and secondary school studies at Comboni College, Khartoum, Sudan, until 1962. He then enrolled at the University of Khartoum until 1965. In 1966, he studied French at Lovanium University, Zaire, and became a teacher. Later, he attended the University of Khartoum again and graduated in 1972 with the degree of Bachelor of Science in Agriculture.

Since then he has been employed as a research assistant in the Horticultural Section of the Agricultural Research Corporation of the Sudan. In 1974, this body sponsored his graduate training in the Department of Fruit Crops of the University of Florida where he obtained the degree of Master of Science in 1976. He continued to pursue his graduate training in this department where he is currently a candidate for the degree of Doctor of Philosophy.

Daniel Apollo Hagillih is a member of the Agricultural Society and the Horticultural Society of the Sudan.

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Robert C. J. Koo

R.C.J. Koo, Chairman
Professor of Horticultural Science

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

A. H. Krezdorn

A.H. Krezdorn
Professor Emeritus of Horticultural Science

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

William S Castle

W.S. Castle
Assistant Professor of Horticultural Science

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

N. Gammon, Jr.

N. Gammon, Jr.
Professor Emeritus of Soil Science

This dissertation was submitted to the Graduate Faculty of the College of Agriculture and to the Graduate Council, and was accepted as partial fulfillment of the requirements for the degree of Doctor of Philosophy.

March 1980

Jack L. Fry

Dean, College of Agriculture

Dean, Graduate School